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WEEKLY 13 November 2021

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Happy, healthy brain

The more we understand about the brain, the more we can do to keep our own in shape. Catherine de Lange shines a spotlight on the latest science of brain health, including what we know about preventing cognitive decline as we age and what we can do to improve our mental well-being. Join us on 3 February 2022 at 6pm GMT (1pm EST) or watch on demand.

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Online

Covid daily briefing

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Podcast

Weekly

Reporter Graham Lawton shares news from COP26 about "game-changing" pledges to cut methane emissions. The team examines new analysis that suggests we could keep global warming within 2°C above pre-industrial levels. And we hear from Larissa Naylor, who started her climate activism when she was 15. Plus: an out-of-this-world story about tardigrades.

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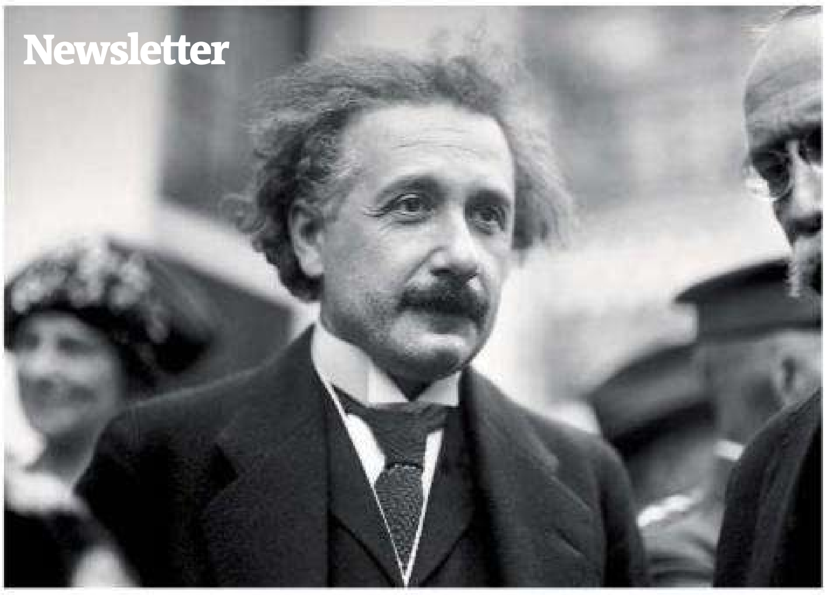

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Climate summit Get all the latest from our reporters at COP26

Video

How to understand everything

We talk to Philipp Dettmer, the founder of science YouTube channel Kurzgesagt, who insists that scientific topics don't have to be hard to understand. He should know, because his films receive billions of views. We have also got videos covering the latest from the COP26 climate summit.

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Newsletter

Lost in space-time

Sign up to get executive editor Richard Webb's physics newsletter free to your inbox. This month, a forgotten idea of Albert Einstein's that might save cosmology, plus the great man's (vain) quest to undermine quantum weirdness and why the universe looks "just right" for our existence.

newscientist.com/lost-in-space-time

Newsletter

> **"Many cosmologists now think 'teleparallel gravity' could be a silver bullet"**

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Our A3-size wall calendar showcases the 12 shortlisted entries from *New Scientist*'s Photography Awards 2021. It features all UK bank holidays, along with key dates in the scientific calendar – perfect for helping you stay organised.

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Digging for victory

Clean energy tech requires a lot of metals, but we must extract them with care

ENVIRONMENTALISTS making the case for a transition to renewable energy have often found the prevailing wind blowing in their faces. Solar and wind power have been dismissed as too expensive, too inefficient, too unreliable or too ugly. In recent years, however, the wind has changed direction. Even if these criticisms were once true, they no longer are.

But there is a counterblast that may yet force the wind to do another U-turn: green energy is very resource-hungry. Building an offshore wind plant, for example, consumes 13 times as many minerals as erecting a gas-fired power plant of equal capacity. According to the International Energy Agency, to hit net zero by 2050, the world will have to increase its production of minerals such as lithium, copper, nickel and the rare earth elements sixfold.

On the face of it, that presents a dilemma. Our planet holds more than enough of the minerals, but getting them out of the ground is difficult without making a hell of a mess. Humans have a huge impact on landscapes generally (see page 30), creating mountains of waste (see page 36). Mining is particularly bad for the environment, though, consuming vast amounts of energy and producing more waste than any other human activity. Scale that up six times and it is tempting to dismiss the renewables transition as a green herring, potentially creating something worse than we already have.

> "The carbon savings from a green transition far outweigh the costs of not doing it"

Tempting, but wrong. Yes, mining as practised is an environmental disaster, but as our feature on page 38 reveals, it doesn't have to be that way. There are huge gains to be made. Chile, for example – which is rich in copper and lithium – is pioneering the transition to zero-carbon mining. New mining technologies likened to keyhole surgery are in development too.

The sixfold figure also ignores the fact that fossil fuels are themselves minerals that have to be extracted at huge environmental cost. Take that into account and the carbon savings from a green transition far outweigh the costs of not doing it. Apologists for fossil fuels may try to smear renewables as being no cleaner, or perhaps even worse. As so often in the past, they would be both wrong and dishonest. ▮

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CONTACT US

newscientist.com/contact

General & media enquiries
UK Tel+44 (0)20 7611 1200
Northcliffe House, 2 Derry Street, London, W8 5TT
Australia 58 Gipps Street, Collingwood, Victoria 3066
US PO Box 80247, Portland, OR 97280

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Indigenous Minga protesters at COP26 in Glasgow

REUTERS/HANNAH MCKAY

Climate summit

Much further to go yet

COP26 pledges so far could limit global warming to 2.4°C – far higher than the 1.5°C goal of the Paris Agreement, reports **Adam Vaughan**

RESEARCHERS have poured cold water on the idea that new emissions plans put forward for COP26 have set the world on course to meet targets that would limit dangerous global warming.

Climate Action Tracker (CAT), an independent, non-profit scientific body based in Germany, said on Tuesday that governmental pledges to curb carbon dioxide emissions by 2030 were "totally inadequate" and would lead to emissions roughly double those needed to hold the temperature rise to 1.5°C this century.

The group's analysis shows that looking only at new country-level targets for 2030, known as nationally determined contributions (NDCs), the world will warm by 2.4°C on average. That is better than the 2.7°C of warming projected before the summit started in Glasgow, UK, but a far cry from the agreement that 195 countries made in Paris in 2015 to keep warming "well below" 2°C and "pursue efforts" for 1.5°C .

The 2.4°C projection is much more sobering than three rapid analyses released last week, by the International Energy Agency, the Energy Transition Commission and a University of Melbourne team. Those variously suggested that the latest NDCs put the world on a path for warming as low as 1.8°C to 1.9°C this century. "The CAT report is a timely cold shower of reality," says Piers Forster at the University of Leeds in the UK.

The report notes that there has been big progress on long-term net-zero pledges, with more than 140 countries representing around 90 per cent of global emissions now having one, including India (see page 8). Those send an "important signal", according to the report, but the lack of action and commitment this decade casts "a long and dark shadow of doubt" over net-zero goals.

The 2030 plans of China, the European Union and the US are judged to have had the most impact on lowering predictions of future warming. India's new 2030 pledges, which include sourcing half of the country's electricity from renewables by 2030, are seen as only offering "mildly" better emissions curbs than current policies.

"What is missing is the implementation, the short-term action, and that is where we have the gap," says Niklas Höhne at the NewClimate Institute, a non-profit research organisation in Germany. Hohne says his group's findings show that waiting until 2025 for countries to submit new plans for 2030, as currently planned, is too late. Instead, he says, COP26 needs to commit governments to keep coming back once a year until the world is on track for 1.5°C and well below 2°C.

On Monday, former US president Barack Obama echoed the view that COP26 had seen progress, but it wasn't enough. "We are nowhere near where we need to be yet," he said, adding that we was "particularly disappointed" that Chinese president Xi Jinping and Russian president Vladimir Putin hadn't attended the summit in person, unlike around 120 world leaders who were there last week.

One key outcome of the Glasgow meeting will be the final statement, known as a "cover decision". A marker of its strength will be what it says about how often countries should revisit their 2030 plans, so that they will be more than greenwashing. Laurence Tubiana, a key architect of the Paris Agreement, said at a press conference on Monday: "Greenwashing is for me now the new climate denial." ▮

Today at COP26
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Climate summit

COP's big promises

The first week of COP26 was dominated by four major announcements on deforestation, methane, fossil fuel financing and India's net-zero plans, reports **Adam Vaughan**

FLORIAN PLAUCHEUR/AFP VIA GETTY IMAGES

Deforestation in Brazil's Mato Grosso state, photographed in 2020

COP26, currently taking place in Glasgow, UK, is a climate summit of two halves. First, there was a week of flashy announcements from world leaders, now there is a week of intense expectation as negotiators attempt to draw up a consensus statement that every participating country will agree to. This huge task was under way as *New Scientist* went to press, but there were four announcements of real significance amid the flurry of pledges from the first week.

Deforestation vow

The summit kicked off with a pledge to end deforestation by 2030, backed by more than 100 countries representing 85 per cent of the world's forests. Significantly, the signatories include Brazil, where deforestation of the Amazon rainforest has been accelerating under President Jair Bolsonaro. There is also new money to help combat forest loss: a £14 billion package coming from 12 countries including the UK, plus private organisations such as the Bezos Earth Fund.

Meanwhile, 30 financial institutions that manage a total of $8.7 trillion in assets announced that they will no longer invest in activities linked to deforestation.

It is "a 'Paris moment' for forests", said Yadvinder Malhi at the University of Oxford, but others worry that there is little detail about how the target will be met, and Bolsonaro's record leaves plenty of room for doubt about his commitment to protecting forests.

"Jair Bolsonaro's record leaves plenty of room for doubt about his commitment to forests"

Methane emissions

More than 100 countries, including the US, Japan and Canada, made what US president Joe Biden hailed a "game-changing" pledge to drive down emissions of methane, a short-lived but powerful greenhouse gas. The Global Methane Pledge commits signatories to reducing their overall emissions by 30 per cent by 2030, compared with 2020 levels. The US government also published a detailed blueprint of how it intends to meet the goal.

Methane is responsible for about 30 per cent of global warming to date, but it has received little attention at previous summits. The new initiative emphasises making cuts by tackling methane leaks from oil and gas wells, pipelines and other fossil fuel infrastructure. Significant amounts of the gas also come from other sources, such as livestock farming and decaying waste in landfill sites.

The voluntary pledge is backed by 15 of the world's biggest methane emitters, including the European Union, Indonesia and Iraq. However, there are some notable omissions, including China, India, Russia and Australia.

Myles Allen at the University of Oxford welcomed the pledge, but said its contribution to climate change needed to be put in perspective compared with carbon dioxide. "People have to realise that methane is not a substitute for reducing CO_2," he said.

India's net-zero plans

Indian prime minister Narendra Modi announced that his country, the world's fourth-biggest emitter, would reach net-zero carbon emissions by 2070. The target is two decades later than that of most other countries, but the move was nevertheless seen as a positive step by campaigners. It means that all major emitters have now declared a deadline for reaching net zero.

Modi made four pledges to meet earlier goals, including getting 50 per cent of India's energy from renewable sources by 2030. India will also aim to cut its projected CO_2 emissions by a billion tonnes between now and 2030 and cut its carbon intensity – the emissions released for each unit of GDP – by 45 per cent.

Fossil fuel finance

Twenty governments promised to stop financing oil, coal and gas projects beyond their borders by the end of 2022. The group, which includes Canada, the UK and the US, is estimated to provide $18 billion of finance a year.

The pledge is also backed by five public banks, including the European Investment Bank.

However, the move doesn't preclude backing domestic projects and allows for exceptions in "limited" circumstances if they are deemed consistent with the Paris Agreement's goals.

The announcement is "fantastic news", says Nina Seega at the University of Cambridge, but needs to be complemented by similar domestic announcements.

Meanwhile, 23 countries committed to stopping new coal power schemes and phasing out existing infrastructure. They included Indonesia, the world's seventh-biggest user of coal power, and Poland, the 13th biggest, with deadlines set in the 2030s for high-income countries and the 2040s for low-income countries.

"The end of coal is in sight," said COP26 president Alok Sharma. But the world's three largest coal users, China, India and the US, didn't sign up to the deal. ■

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Ancient humans

Infant skull suggests *Homo naledi* buried their dead 250,000 years ago

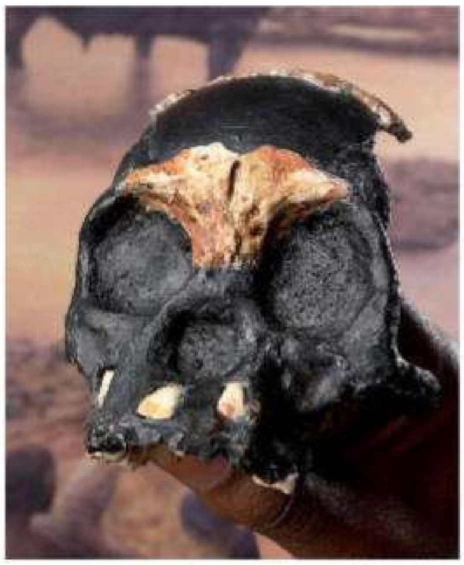
Michael Marshall

THE skull of a small child belonging to a different human species has been found deep in a cave system in South Africa. The team that made the discovery has named the child Leti and believes the skull shows that the *Homo naledi* species buried their dead.

Leti's skull was found in a narrow fissure that is almost impossible to access. Presenting their findings at a virtual press conference on 4 November, the researchers said it is evidence that hominins have been performing funerary rights for hundreds of thousands of years – even hominins with brains much smaller than ours. "We can see no other reason for this small child's skull being in the extraordinarily difficult position," said Lee Berger at the University of the Witwatersrand in Johannesburg, South Africa.

Berger and his colleagues have been exploring the Rising Star cave system in South Africa for several years. In 2015, they described a new species of hominin found in the caves, which they called *Homo naledi*. It had features that resembled modern humans, but in other respects it looked like an older species: in particular, its brain was small.

Two years later, the researchers found a complete *H. naledi* skeleton in another part of the cave. Crucially, the team managed to narrow down how long ago *H. naledi* lived. The remains are only about 250,000 years old, meaning *H. naledi* existed at the same time as our species and other big-brained hominins like the Neanderthals – yet they retained features from species that lived millions of years earlier.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The skull fragments appear to come from a 4-to-6-year-old child

In September 2017, the team was exploring deeper parts of the cave. Marina Elliott of Simon Fraser University in Burnaby, Canada, was one of the researchers who went in. She had to go through a room dubbed the Chaos Chamber. "There's boulders that have fallen from the ceiling," she said. "Then there's a little bit of a drop into a crawlspace that just literally leads into a couple of small, narrow passages." These passages are only tens of centimetres across, so the researchers had to turn sideways and even partly upside down to get inside.

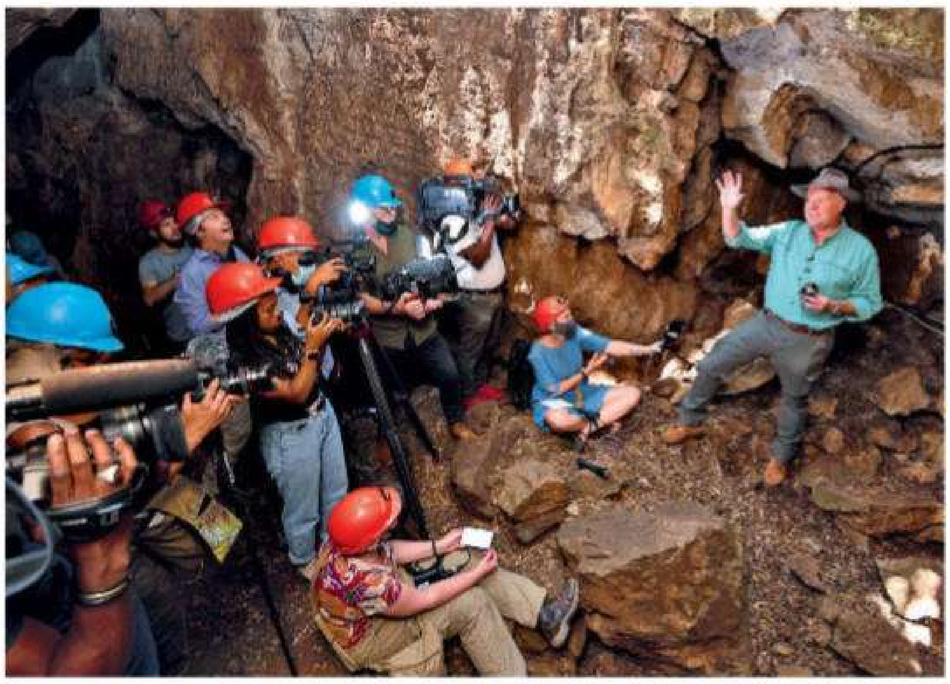
In one such passage, about 20 centimetres across and 80 centimetres tall, the researchers found a small ledge. Sitting on it were 28 fragments of skull and six teeth. When the researchers brought the remains back to the surface, they realised they probably belonged to one individual, who they named Leti, from the Setswana word *letimela*, meaning "the lost one".

The team has now described Leti, and the surrounding caves, in two papers (*PaleoAnthropology*, doi.org/g46n; doi.org/g46p). Two of the teeth were milk teeth and four were adult but looked like they had only recently emerged from the gums. Based on this evidence, "Leti was probably somewhere between 4 and 6 years of age", said team member Juliet Brophy of Louisiana State University in Baton Rouge.

Leti probably dates back to the same time as the other *H. naledi* remains, said Tebogo Makhubela at the University of Johannesburg in South Africa, who was also involved in the work.

"It is an absolutely amazing and remarkable site," says Emma Pomeroy at the University of Cambridge, who wasn't involved in the studies. Having the skull of a child will help us understand how *H. naledi* individuals changed as they aged. Such patterns of growth "are what distinguish humans and other related species", she says.

Lee Berger (right) has been exploring South Africa's Rising Star caves


BRETT ELOFF PHOTOGRAPHY

From the start, Berger has suggested that the *H. naledi* bones were placed in the cave system deliberately by other *H. naledi*, after individuals died. "I think it's fair to say it was controversial in 2015 to say a small-brained, primitive-looking hominin might have been deliberately disposing of its dead," he said. The discovery of Leti, even deeper into the cave system, adds to the evidence, Berger argued. On this reading, Rising Star is a *H. naledi* grave.

> "We see no other reason for this small child's skull being in an extraordinarily difficult position"

Other potential explanations seem unlikely, said team member Darryl de Ruiter of Texas A&M University in College Station. "There's no indication of any carnivore activity: no tooth marks, no gnawing, nothing like that," he said. That means it is doubtful that other animals carried the bones into the caves. "There's no indication that there's a large-scale water movement depositing these things," he added.

"I think it's still not 100 per cent certain," says Pomeroy. She says that carnivores and floods are unlikely to be the cause, but there are other possible explanations. One is that a group of *H. naledi* went into the caves, perhaps for shelter, but got lost and died inside. "It does look like this network where you could quite easily get lost and it would be hard to get out." ■

Space

Did Earth grow from an alien rock?

A new idea could explain how our planet began to form billions of years ago

Jonathan O'Callaghan

INTERSTELLAR objects may have seeded the creation of planets in solar systems like our own, potentially solving a key problem with planet formation theories.

In 2017, researchers observed an object from another solar system passing through our own for the first time. They named it 'Oumuamua, and the general view is that it was some sort of asteroid or comet ejected from its host star system.

A second interstellar object, comet Borisov, was seen in 2019. The detection of 'Oumuamua and Borisov suggests that there are many interstellar objects travelling around our galaxy at any given moment.

This further indicates that such objects could play a role during the birth of solar systems. The slow speed of young stars relative to their neighbours, coupled with the braking effect of the dust and gas that surround them, could cause these objects to enter orbit around a star rather than simply passing through like 'Oumuamua and Borisov.

Amaya Moro-Martín and Colin Norman at the Space Telescope Science Institute in Baltimore, Maryland, modelled this process to estimate how many objects might become trapped by an average young star. They suggest that, over a period of maybe 10 million years, 600 billion objects about 1 metre in size would be captured, along with a further 200 million that are 10 metres wide, 60,000 that are 100 metres across and 20 that are 1 kilometre wide (arxiv.org/abs/2110.15366).

"We were surprised that these numbers were pretty high," says Moro-Martín. "But it is very uncertain, because we don't really know how much material is out there."

The figures suggest that interstellar objects could seed the birth of planets. These are thought to form by the accumulation of matter, gained either by accreting small, seed-like objects known as pebbles or through the collision of asteroid-like bodies known as planetesimals. But how you grow from dust in a disc to these larger objects is an open problem, known as the metre-size barrier.

NASA/ESA/STSCI/JPL

An artist's illustration of the interstellar object 'Oumuamua

"When dust particles become larger, their collisions are more energetic," says Moro-Martín. "When they collide, they start bouncing [off one another] rather than aggregating."

Interstellar objects could enable this material to accumulate, a little like the process through which dust in a cloud on Earth seeds raindrops. "These bigger bodies effectively act as condensation nuclei," says Michele Bannister at the University of Canterbury in Christchurch, New Zealand.

This might indicate that we owe our very existence to material from another star, says Alan Fitzsimmons at Queen's University Belfast in the UK. "It's possible that Earth was started by an interstellar object sitting in the sun's protoplanetary disc," he says. The object would form only a tiny fraction of our planet's bulk and almost certainly wouldn't be detectable today.

Some of these trapped objects could remain in the outer reaches of our solar system, however, perhaps in the Kuiper belt or Oort cloud beyond Neptune. But identifying one would be "pretty tough", says Fitzsimmons. ▮

Palaeontology

Penis worms lived in borrowed shells long before hermit crabs

HUNDREDS of millions of years before hermit crabs existed, penis worms took on a similar lifestyle – suggesting that the world's earliest animal ecosystems were more ecologically sophisticated than previously thought.

Marine animals similar to some that are still alive today appeared during the Cambrian explosion, about half a billion years ago. But early marine ecosystems are thought to have been simple, which makes the discovery of fossils showing priapulids – known as penis worms for their phallus-like shape – hiding inside snail-like shells a surprise. "Grabbing a shell... takes a level of behavioural complexity to say, 'Well, I need to find a shell that I fit in'," says Martin Smith at Durham University, UK.

He and his colleagues at Yunnan University in Kunming, China, discovered the fossils in 530-million-year-old rocks from the Guanshan biota, a fossil deposit in southern China. Four of the penis worms were found nestled down inside the conical shells of hyoliths (of the genus *Pedunculotheca*), an extinct, mollusc-like animal (*Current Biology*, doi.org/g49v).

This marks the earliest evidence of such behaviour: hermit crabs didn't adopt this sort of lifestyle until about 170 million years ago in the middle of a later evolutionary "explosion" called the Mesozoic marine revolution. During this time, predation stepped up a notch, says Smith – a little like the invention of a new technology for waging war.

Finding hermit crab-like behaviour in animals that lived far earlier in geological time is "like finding a picture of a cannon in the Bayeux Tapestry", says Smith. ▮

Christa Lesté-Lasserre

"Finding hermit crab-like behaviour in these animals is like finding a cannon in the Bayeux Tapestry"

Blackmagicdesign
ATEM Mini Pro model shown.

Introducing ATEM Mini Pro

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Technology

Prize for predicting path of a ‘message in a bottle’

David Hambling

SOFAR OCEAN

One of the solar-powered sensors used in the challenge

A MESSAGE in a bottle dropped in the ocean may be found years later somewhere completely unexpected; the routes taken by such bottles have been an enduring mystery of the sea. This month, researchers will attempt to tackle that mystery and compete for a $50,000 prize in the Forecasting Floats in Turbulence competition, sponsored by the US Defense Advanced Research Projects Agency (DARPA).

Oceanographers have an accurate picture of the patterns of “coherent” ocean currents that operate on a scale of tens of kilometres or more. But these are surrounded by smaller currents moving in other directions, so predicting the motion of a drifting object is far from straightforward.

“This is a chaotic system, so small errors in drifter location or velocity can quickly lead to very different results,” says Nikolas Aksamit at the University of Victoria in Canada. “If your model puts a drifter slightly on the wrong side of one of these coherent structures, it’s similar to the difference between a car getting off the highway at an exit or missing the exit.”

Depending on exactly where it is, a drifting object may loop around in an eddy, get becalmed or change direction.

29,000

Number of toys lost at sea and used to map currents in 1992

DARPA programme manager John Waterston, who is running the competition, says success will rely on better computer models with high enough resolution to deal with smaller-scale currents. Imagine low-resolution 8-bit graphics compared with the 4K graphics of today, he says. “The math to move between these regimes is filled with uncertainty and chaos,” says Waterston.

Mapping currents has improved since the days when researchers relied on drift bottles instructing the finder to write back with their location, supplemented by convenient accidents. One such accident helped map currents for years: after 29,000 plastic bathtub toys were lost from a cargo ship in the Pacific in 1992, researchers logged the locations of the toys as they washed up on the coast of the US and Canada. Modern drifting sensors often have satellite tracking, but prediction is still difficult.

The challenge began on 3 November, with DARPA releasing the exact locations of 90 drifting solar-powered sensors from US firm Sofar Ocean in the Atlantic each day for 20 days. At the end of that period, competitors must provide predictions of the expected sensor locations for another 10 days. The scoring favours long-term accuracy: a prediction within 32 kilometres on day 10 scores more than an accuracy of 2 km on day one.

Aksamit notes that competitors may benefit from recent improvements in modelling fluid flows. His own research has also looked at how machine learning can help by filling in the gaps when detailed information isn’t available.

The immediate aim of the project is to assist DARPA’s Ocean of Things, a plan for a vast array of drifting sensors for extended monitoring missions. Better understanding of drifting will help decide where to drop these devices to ensure there is maximum coverage. Improved current prediction will also be useful for tasks like anticipating the spread of oil spills and other pollution, and helping searchers locate survivors after accidents and ship sinkings. ▮

Animal behaviour

Chimpanzees don’t like the smell of death

Christa Lesté-Lasserre

CHIMPANZEES avoid the smell of dead things, much like we do.

It is thought that humans and some other animals evolved disgust for putrescine – the chemical odour compound associated with decomposing bodies – to protect them from disease or predation by scavengers. However, nobody had tested whether chimpanzees were sensitive to the smell of death, says James Anderson at Kyoto University in Japan.

He and his colleagues investigated this with two female and four male chimpanzees, all aged between 24 and 48 years old, that were housed in Kyoto University’s Kumamoto Sanctuary.

One night a week over a six-week period, the chimpanzees returned to their cages after roaming in the sanctuary to find either a stuffed dead bird or a stuffed glove in a cardboard box just outside their cages. The researchers dispersed odours from a bucket, using a fan to waft the scents of water, putrescine or other substances.

The chimpanzees avoided the object significantly more when putrescine was diffused, regardless of whether it was a bird or a glove, says Anderson (*Behavioural Processes*, doi.org/g48s).

“With the putrescine, it was clear that the chimps wanted away from there,” he says. The two oldest individuals, aged 46 and 48, were the least repulsed by the smell of putrescine.

Chimpanzee mothers sometimes carry dead infants for weeks or months, even as their odour increases. The researchers didn’t test such mothers, but they suspect that these apes accept the odours due to attachment to their infants, or they might just get used to the smell. Post-partum chimpanzees may also have a reduced sense of smell, but studies would be needed to test this, says Anderson. ▮

Antibiotic resistance

CRISPR-based ‘antibiotics’

Harmful bacteria could be targeted by benign ones with genetically engineered weapons

Michael Le Page

A BENIGN bacterium armed with a designer, CRISPR-based weapon has been used to eliminate a harmful bacterium from the guts of mice while leaving all other microbes there unharmed.

The approach could give us a new way of tackling antibiotic-resistant infections of the gut and skin, says Sébastien Rodrigue at the University of Sherbrooke in Canada. Others have shown that this approach works in cells grown in dishes, but Rodrigue’s team is the first to get it to work effectively in animals. “If it works in mice, it should also work in other animals, including people,” he says.

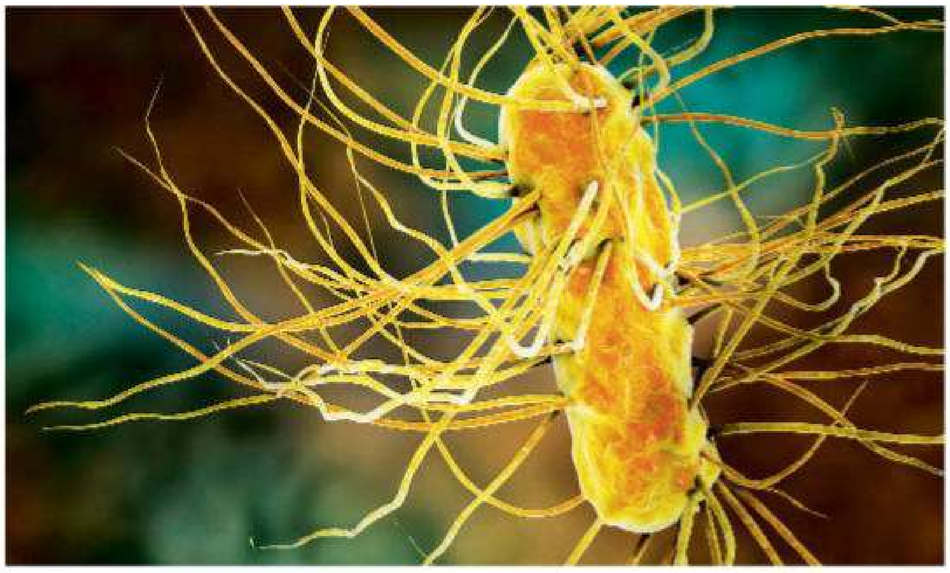
CRISPR is best known as a gene-editing tool, but it can also be programmed to kill bacterial cells that have specific bits of DNA inside them. The hard part is that doing this requires getting a CRISPR system inside every single one of the bacterial cells that you want to kill. “The real challenge is the delivery,” says Rodrigue.

One way to deliver CRISPR is to exploit circular bits of DNA within bacteria known as conjugative plasmids. These carry genes that make the bacteria pass them on to other bacterial cells via a process called conjugation.

Rodrigue’s team tested different plasmids in a common group of bacteria to find the one that was most effective at transferring itself. The group then evolved it in the lab to make it even more efficient.

The team added the genes for a CRISPR system targeting an antibiotic-resistant strain of *E. coli*, and put the plasmid inside a benign bacterium used as a probiotic. When the CRISPR-armed probiotic bacteria were given to mice, they eliminated 99.9 per cent of the *E. coli* bacteria in four days.

E. coli bacteria can be targeted with a CRISPR-based weapon



KATERYNA KON/SCIENCE PHOTO LIBRARY/ALAMY

Next, the team targeted a bacterium called *Citrobacter rodentium* that damages the guts of mice it infects. The CRISPR-armed probiotic bacteria cured infections within four days. “It completely eliminated the *Citrobacter rodentium*,” says Rodrigue. The team has now begun testing the method in pigs, where it could provide an alternative to the antibiotics widely used by farmers (*Molecular Systems Biology*, doi.org/gm7s6z).

The method is very efficient, says Alejandro Chavez at Columbia University in New York. “Overall, an approach like this is certainly possible.” But there are potential risks with such efficient conjugative plasmids, says Chavez. If something went wrong, the plasmids might end up spreading undesirable genes.

To stop this happening, Rodrigue plans to ensure that the plasmids don’t persist after treatment. One way to do this is to delete the genes that the plasmids need to replicate, so they soon die out. Another is to make the CRISPR system target and destroy the plasmids after a certain delay, in a timed self-destruct system.

The CRISPR-armed probiotic bacteria effectively act as a highly selective antibiotic. They could be used to treat infections wherever bacteria can survive in the body, from the skin to the bladder. ▮

Neuroscience

Tiny region of the brain that regulates sleep studied at last

WE HAVE taken our closest look yet at the activity of a tiny brain region thought to be involved in the human circadian clock.

Johanna Meijer at Leiden University in the Netherlands and her colleagues have been studying the suprachiasmatic nucleus, which sits in the hypothalamus and is thought to play a role in regulating our sleep cycles. However, because this structure is so diminutive – measuring less than 2 millimetres across – it is difficult to image using an MRI scanner. That means it is challenging to record its activity.

The researchers got around this problem using an MRI machine with a particularly powerful 7-tesla magnetic field. This offers sufficiently high resolution to image this tiny part of the brain.

There are only about 90 7-tesla MRI scanners in the world. The team used one of them to study suprachiasmatic nuclei in the brains of 12 men. Meijer says these nuclei are the smallest brain structures to have been imaged in living people.

However, to then study a suprachiasmatic nucleus’s activity pattern, the researchers needed to be able to shine lights of various frequencies into the eyes of the individuals who were inside the MRI scanner and monitor how the nucleus responded.

This was a challenge because standard LED lights would be affected by the unusually powerful magnetic field and radio pulses inside a 7-telsa MRI machine.

> **“The suprachiasmatic nucleus is the smallest brain structure imaged in a living person”**

To get around this, the researchers custom-built an LED with voltage suppressors and shielding to function under such conditions (bioRxiv, doi.org/g4wt).

“I think that the method they’re using has a lot of potential,” says Debra Skene at the University of Surrey in the UK. However, she says the researchers used such bright pulses of light to elicit a response from the nucleus that it is unclear if this particular study tells us anything new about circadian clocks. ▮

Jason Arunn Murugesu

Vaccines

Preparing for the next pandemic

The risk of a deadly flu pandemic is an ever-present danger, but progress on a universal vaccine could protect us, reports **Michael Le Page**

JEFFREY GREENBERG/UNIVERSAL IMAGES GROUP/GETTY IMAGES

A universal flu vaccine could rule out the need for an annual flu shot

FED up with this whole pandemic business? Unfortunately, another one could start any day. In particular, a flu pandemic remains an ever-present threat.

"It's not a question of if, but when," says Peter Palese at the Icahn School of Medicine at Mount Sinai, New York. That is why he and many others are trying to develop a vaccine to tackle the next flu pandemic before it even starts – a so-called universal flu vaccine that protects against all flu viruses.

"The advances in technology have been extraordinary," says Palese. "We know a lot about the structure [of flu viruses], we know a lot about the immunology, which we didn't know five years ago. I think we are poised to have a universal flu vaccine."

There is no doubt about the seriousness of the threat. Seasonal flu viruses already in circulation kill around 400,000 people worldwide every year, despite an annual campaign to vaccinate against them (see "Will 2021 be a bad year for flu?", right). And when animal flu viruses jump to people, they can be far more deadly. A bird flu virus was the cause of the 1918 H1N1 flu, which may have killed 1 in 20 people alive at the time.

There have been four other flu pandemics since then, though fortunately all were much less lethal. But the ever-growing number of farmed birds and pigs provides a breeding ground for flu viruses and opportunities for them to infect humans, meaning the danger hasn't gone away.

Already this year, there have been 25 human cases of H5N6 bird flu in Asia. Between 2014 and 2020, there were just 26 cases in total. Half of those known to be infected have died. With every person infected, there is a risk of the virus mutating and acquiring the ability to spread readily from person to person, sparking a pandemic.

400,000
Worldwide deaths from seasonal flu each year

25
Cases of H5N6 bird flu in people in Asia so far this year

26
Cases of H5N6 bird flu in people in Asia between 2014 and 2020

Existing flu vaccines wouldn't help if this happened. They prompt our immune system to produce antibodies that bind to the head of the haemagglutinin proteins (the H in H1N1) on the outside of the virus. These antibodies can be great at stopping the virus infecting cells, but the head is also the part of the virus that mutates the most. As a result, the antibodies we produce against one flu strain soon become ineffective against its descendants. This is why new flu vaccines have to be produced every year and why these vaccines provide no protection against potential pandemic strains.

To create universal flu vaccines, most researchers are taking one of two broad approaches. The first is to target other external parts of the virus that change much less than the head, namely the stalk of haemagglutinin.

"The critical, highly conserved haemagglutinin stem region is the basis of the universal influenza vaccines," says Wayne Marasco at Harvard Medical School.

In 2009, his team showed that antibodies targeting parts of the stalk can protect mice from a broad range of flu viruses, including the H1N1 strain from 1918. The big challenge, then, is to create a vaccine that makes our immune systems generate a strong antibody response to the stalk, rather than the head.

Stalk solution

Researchers are trying several methods. One is to create vaccines that contain only parts of the stalk, rather than the entire haemagglutinin. Another, which Palese's team is testing in initial human studies, is to use haemagglutinins with the same stalk but different heads. Giving these in sequence boosts the normally weak antibody response to the stalk.

To add to the challenge, the stalks of certain flu viruses are different enough that a

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single vaccine won't work, says Palese. At least three will have to be combined.

The second broad approach fires up a different part of the immune system by eliciting a T-cell response. When cells are infected by a virus, they display the viral proteins on their surface. Immune cells called T-cells learn to recognise these proteins and destroy any infected cells. This method isn't limited to targeting external viral proteins because infected cells also display internal viral proteins.

> **"If a universal flu vaccine reduced deaths by 95 per cent, I think we would all be very happy"**

One downside of relying on T-cells is that, unlike antibodies, they don't prevent cells being infected in the first place. But proponents argue that targeting the slower-changing internal proteins is a better long-term bet.

"Continuing to produce antibody-based vaccines is just shooting yourself in the foot," says Olga Pleguezuelos at UK-based company SEEK, which has created a T-cell vaccine called FLU-v based on key parts of internal proteins.

A small, early human trial suggests it works, but not particularly well: of those given the vaccine candidate, 33 per cent developed symptoms when deliberately exposed to a flu virus compared with 55 per cent of the unvaccinated.

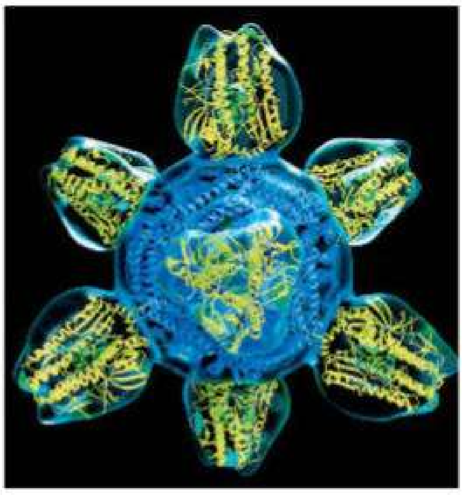
Pleguezuelos says these results don't necessarily reflect how well FLU-v might protect older people. The volunteers were all young and healthy, she says, and exposed only to a mild flu strain. As we are seeing with the coronavirus, vaccines can still work well to prevent severe illness even if the protection they provide against infections is more modest.

SEEK hopes to do large-scale human trials to see how well FLU-v protects people in the real world, but the low flu levels brought about by the various restrictions imposed during the pandemic have made this impossible.

Ultimately, the best results might come from merging the antibody and T-cell approaches. "Sometimes, what is going to be best is just a combination of everything," says Pleguezuelos.

But making proteins is expensive, and doubling the number in a vaccine doubles its cost. This is where mRNA vaccine technology, used in the highly effective covid-19 jabs produced by Moderna and Pfizer/BioNTech, could help. With these vaccines, people's bodies take on the normally expensive job of protein manufacture, making it feasible to include more components.

"RNA vaccines provide you with the option of starting to combine approaches," says Pleguezuelos. "If you deliver [proteins] as RNAs, you can start targeting the stalk, targeting the T-cells, targeting absolutely everything you want."


SCIENCE HISTORY IMAGES/ALAMY

An artist's impression of a prototype universal flu vaccine

Globally, a dozen or so potential universal flu vaccines are being tested in people, with many more at earlier stages. There is no guarantee any will work – some promising candidates have already proved ineffective. But with all the advances in technologies and the greater effort being put in, many think it is now only a matter of time before we have a vaccine that at least provides broader, longer-lasting protection than existing annual ones.

It is unlikely that a single vaccine will ever give people lifelong protection from every flu virus they might encounter, not least because flu viruses might evolve in response to a successful universal vaccine. In fact, the US National Institutes of Health, which is prioritising the creation of a universal flu vaccine, says it need provide protection only for a year at least. But Palese thinks a decade or two is achievable.

The sooner we can start vaccinating people, the more prepared we will be for another flu pandemic. Coronavirus vaccines were rolled out in record time, but many people are still dying because they have yet to receive one. Nearly two years on from the start of the pandemic, only half the world's population has had at least one dose of vaccine. The hope with a universal flu vaccine is that most people can be given it in advance, saving millions of lives even if it doesn't provide complete protection. "If it reduced deaths by 95 per cent, I think we would all be very happy," says Palese. ▮

Will 2021 be a bad year for flu?

The flu vaccines dished out annually are effective only against the specific strains they target. But because the vaccines are grown slowly in hen eggs, manufacturing has to begin around nine months in advance, before it is clear which strains pose the greatest threat.

Predicting which strains to include in the vaccine is difficult even in normal times. "Sometimes the prediction is right, sometimes it's not," says Olga Pleguezuelos at UK-based biomed company SEEK.

But this year is unlike any other. "It's extremely difficult to predict what's coming. This is why health systems are very scared," says Pleguezuelos. "You just don't know what's coming."

Health officials in the northern hemisphere usually look at which flu strains are circulating in the southern hemisphere, but there has been almost no flu during the coronavirus pandemic. "There was basically nothing in Australia and New Zealand during their winter time," says Peter Palese at the Icahn School of Medicine at Mount Sinai in New York.

Because our immunity to flu will have waned during the pandemic, it is possible that flu could return with a vengeance now restrictions have eased in most countries. But it is also possible that circulating strains have had less chance to evolve during this period. In fact, it appears one major human flu lineage, called B/Yamagata, has gone extinct.

According to the latest World Health Organization update, there are still fewer flu cases globally than normal for this time of year. But it is the combined number of flu and covid-19 cases that hospitals have to cope with, and no one is sure what the northern winter will bring.

Neurology

Brainless sponges have cells that may be the precursors to neurons

Michael Marshall

SHUTTERSTOCK/ALLEXXANDAR

Sponges may be the oldest animal group still living today

SPONGES lack anything resembling brains, but they contain cells that have some of the capabilities of neurons – and these may be the evolutionary precursors of true brain cells.

"The nervous system came about very early in animals and this transition is completely enigmatic so far," says Detlev Arendt at the European Molecular Biology Laboratory in Heidelberg, Germany. Most animals have brains, or at least neurons, the cells that are their building blocks. Neurons carry electrical signals and communicate with each other by releasing chemicals, often at junctions known as synapses.

Sponges are the exception. They are one of the oldest animal groups still extant – possibly the very oldest. And they don't have anything that looks like neurons, synapses or brains, says Jacob Musser, also at the European Molecular Biology Laboratory. But he, Arendt and their colleagues have found that sponges might have precursors of these things.

The researchers studied a freshwater sponge called *Spongilla lacustris*. They broke apart sponges and tracked individual cells to see which genes were active. The sponges had 18 distinct cell types, each with a different pattern of gene activity. The team then stained the cells to see where they were within the body. One cell type stood out. The team calls them "neuroid" because they had long tendrils, resembling neurons.

> **"There are neurons in a variety of different animals that share features with digestive cells"**

Their gene activity suggested they secrete signalling chemicals, similar to those that neurons release. They were found in the sponge's digestive chamber (*Science*, doi.org/g4xt). Arendt and Musser say there is growing evidence that some neurons evolved from digestive cells.

"There are neurons in a variety of different animals that share a lot of features with digestive cells and even come from some of the same embryonic precursors," says Arendt. However, other neurons have more in common with cells that contract, such as muscle cells, and may represent a separate origin of neurons.

Arendt emphasises that the sponges' neuroid cells aren't neurons. "We still think they don't have a nervous system," he says. But these cells may coordinate the activities of the digestive cells. "We see a lot of vesicles in those neuroid cells that would indicate that they secrete something, which is a very strong indication for communication," he says.

Sponge biologist Sally Leys at the University of Alberta in Canada describes the data as "superb". But she is unconvinced by the interpretation. "I think there's no evidence shown in this paper that these are anything to do with a neuroid precursor at all."

Leys argues that many of the genes the team focused on are widely used in complex organisms and aren't specific to neurons. The sponges may be using them for other purposes. ▮

Space

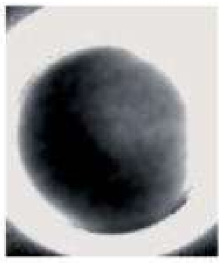
We have had a good look at Pluto's dark side for the first time

MOONLIGHT on Pluto has revealed some features of the dwarf planet's shady side to us.

On its way past Pluto in 2015, NASA's New Horizons spacecraft turned around and took pictures of this distant world's back. After a lengthy cleaning-up process, the images have revealed some of the first details of the side facing away from the sun at the time.

Taking photos of Pluto from beyond its orbit is difficult because at that position, it is backlit by the sun. "It's like driving in a car with a dirty window, looking into the sun without a sun visor, trying to read a street sign," says Tod Lauer at the US National Optical Infrared Astronomy Research Laboratory in Arizona, who is part of the New Horizons team.

But there is some light bathing the dark side, courtesy of Charon, Pluto's biggest moon. Charon is much smaller than Earth's moon, but it is shinier and closer to its host world than our satellite, so it provides an appreciable amount of light to the side of Pluto that is facing away from the sun.



NASA/JHAPL/SWRI/NOIRLAB

The dark side of Pluto illuminated by light reflected from its moon

Under this faint illumination – and after image processing to strip out the sunlight coming from behind Pluto – the researchers found one spot that was brighter than its surroundings, which is probably a deposit of nitrogen or methane ice.

They also found that the south pole appeared to be much less bright than the north pole (arxiv.org/abs/2110.11976). "You expect the poles should be more or less the same, and this difference is intriguing – it may indicate a seasonal thing," says Lauer.

New Horizons flew by Pluto at the end of the small world's southern summer, so this may be a hint that bright ice deposits don't survive that warmer period, or that haze particles from the tenuous atmosphere are deposited on the surface in the summer. ▮

Leah Crane

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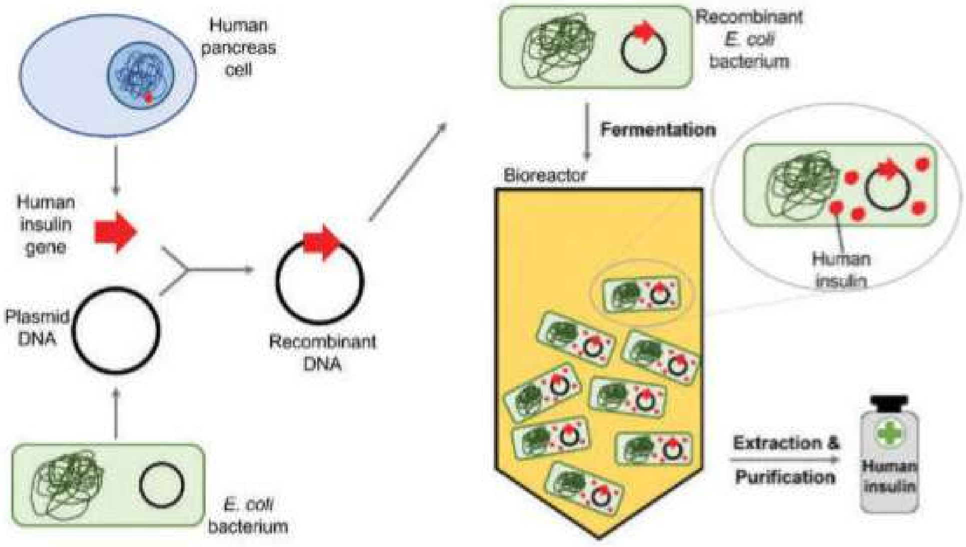
Better Biotherapeutics

Patrick Ingle and Raquel Rodrigues: SBRC – Nottingham

Synthetic biology seeks to create or redesign new biological parts or systems already found in nature. Its approaches have enormous medical potential in the form of biotherapy. Biotherapeutics are medicines which are obtained from biological sources, rather than from chemical synthesis. They can be divided into two main groups: biologics, which contain small molecules produced by microorganisms and live biotherapeutic products, which contain whole, live microorganisms.

The first licensed biotherapeutic was human insulin in 1982. This was produced using recombinant DNA technology by cloning and expressing the genes encoding human insulin in *E. coli*. Prior to this, insulin had been harvested from the pancreas of cows and pigs. In the following decades, hundreds of biotherapeutics have been brought to market, including monoclonal antibodies, hormones and growth factors, for the treatment of chronic diseases such as cancers and rheumatoid arthritis



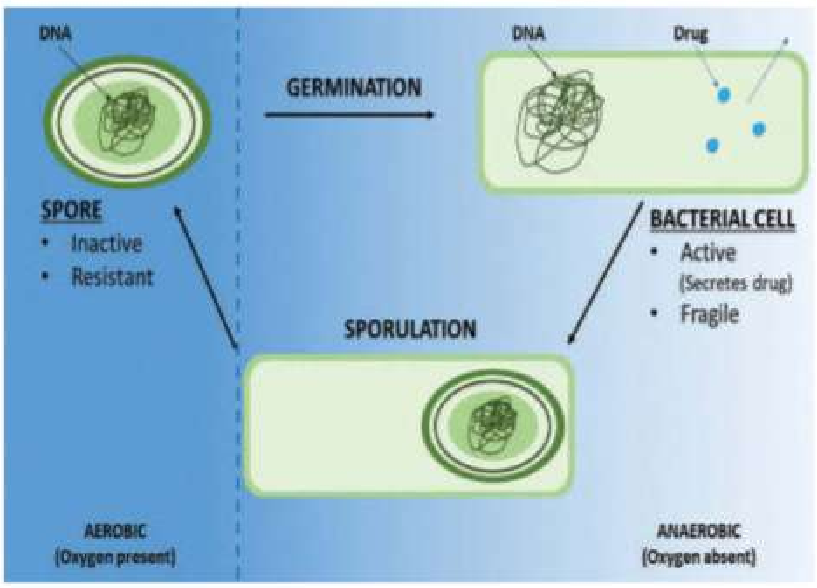
One of the main challenges associated with cancer therapy is the fact that cancer cells are, in fact, human cells that escape control and multiply too much. They are almost indistinguishable from healthy cells, so cancer treatments frequently affect normal cells in addition to tumours, leading to severe side effects. One way to make cancer therapies targeted is to use bacterial spores as delivery vehicles. These "hibernating" bacteria will remain inactive in most of our body and become activated exclusively in certain tumours due to the lack of oxygen. Therefore, if we engineer bacteria to deliver a cancer treatment, that treatment will affect only tumours and side effects will be minimised.

SBRC-NOTTINGHAM is a UKRI BBSRC/EPSRC funded, Synthetic Biology Research Centre led by Professor Nigel P. Minton at the University of Nottingham, UK. SBRC–Nottingham aims to provide new technologies in the form of engineered bacteria and processes that together can be used at scale by industry and medicine to improve the health of our population and our planet.

For more information visit:
https://sbrc-nottingham.ac.uk/

SynBio
SBRC Nottingham
a BBSRC/EPSRC Synthetic Biology Research Centre

Researchers at the SBRC-Nottingham are studying the spore-forming bacterium *Clostridium* spp. to deliver therapeutic drugs in a targeted manner. Spores are inactive versions of bacteria that can survive under conditions that would normally kill them – as if the bacteria were hibernating to survive. The bacteria studied at the SBRC-Nottingham cannot tolerate oxygen, so if spores are administered to a patient, they will remain inactive until they find a spot in our body that lacks oxygen. This allows the targeted delivery of therapeutics to specific organs, avoiding side effects, which is particularly useful in cancer therapy.



About us

***Patrick Ingle** is a postdoctoral research fellow in the health group within the SBRC-Nottingham. His research interests are in bacterial sporulation/germination and understanding how resident gut microbes provide colonization resistance against bacterial pathogens.*

***Raquel Rodrigues** is a postdoctoral research fellow in the SBRC. She studies sporulation in harmless bacteria with the aim of improving a targeted therapy for cancer.*

Astronomy

Plan to image another Earth

A report on priorities for the next decade in US astronomy recommends building a telescope that could show us a habitable Earth-like planet, reports **Leah Crane**

THE US astronomy community has laid out its priorities for the coming decade in a massive report that recommends, among other missions and observatories, the creation of an $11 billion space telescope designed to investigate Earth-like worlds beyond our solar system.

Every 10 years, US science agencies task the National Academies of Sciences, Engineering, and Medicine with identifying the top research priorities of the entire US astronomy and astrophysics community in a process called the decadal survey.

The report laying out the goals for 2022 to 2032, titled *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*, was born from almost 900 white papers and more than two years of discussions among a group of 127 experts. It was released on 4 November.

The largest of the recommended missions is an enormous space telescope designed to be the successor to the James Webb Space Telescope (JWST), which itself was the highest priority of the 2001 decadal survey. After many delays and budget problems, it is scheduled to launch this December.

"JWST is going to look at a wide variety of planets, but those worlds will not look like our own," says Jonathan Fortney at the University of California, Santa Cruz, who was part of the steering committee that assembled the report. "The big flagship telescope that we're recommending that we get started on, that'll be a mission to characterise systems that do look like our own for the first time."

This new telescope will be designed to someday take a direct image of a habitable Earth-like planet. The report states that with sufficient investment, the telescope could start being designed before 2030 and launch in the mid-2040s.

Partly motivated by the many logistical issues with JWST, the report also recommends a new way of developing such missions: continuously investing in the development of the technology for major observatories, so that by the time the final mission is conceptualised, the technology it will require will be close to being ready. That will make it easier to accurately estimate budget and time requirements.

This programme is the spiritual successor to NASA's Great Observatories programme, which produced four powerful space telescopes between 1990 and 2003, starting with the Hubble Space Telescope.

"In changing how we plan for the most ambitious strategic space projects, we can develop a broad portfolio of missions to pursue visionary goals, such as searching for life on planets orbiting stars in our galactic neighborhood – and at the same time exploit the richness of 21st century astrophysics" across the spectrum of wavelengths used for astronomical observations, said Fiona Harrison at the California Institute of Technology, who was also part of the decadal study's steering committee, in a statement.

> "The flagship telescope will be used to characterise systems that look like our own for the first time"

This variety of observations will be crucial for all three prongs of astrophysical research identified as priorities in the report: finding habitable worlds, understanding black holes and neutron stars and learning how galaxies form and evolve.

"These missions take such a long time that you cannot estimate the cost of a mission when you know the technology will take a decade to be developed and the mission will take two decades to fly," says Gabriela González at Louisiana State University, who was part of the decadal survey steering committee, too.

The report also advocates for beginning the development of several other missions, including space telescopes that observe in X-rays and the far infrared. These could help us understand the early days of galaxy growth and the formation of other important astrophysical objects.

Aside from these major space-based observatories, the survey recommends investing in several less expensive ground-based facilities, particularly those that fall under the US Extremely Large Telescope Program, plus upgrades to the Laser Interferometer Gravitational-Wave Observatory in Washington and Louisiana and the Very Large Array in New Mexico. It also recommends funding new facilities to observe the cosmic microwave background and neutrinos.

Now that the report has been delivered to the government agencies that organise and fund much of US science, following through on it is in their hands. "In my experience, what I've seen is that the agencies really try hard to make these recommendations happen – they see it as the whole astronomy community speaking with one voice about what the priorities should be," says Fortney.

"Not all of these things are going to happen, but I have every confidence that both Congress and the national agencies take this really seriously and I think that a lot of these recommendations really will come to fruition," he says. ■

An $11 billion exoplanet-hunting telescope could launch in the mid-2040s

DETLEV VAN RAVENSWAAY/SCIENCE PHOTO LIBRARY

Animal behaviour

Separation anxiety may be worse in dogs left with others

Christa Lesté-Lasserre

JOEFOX LIVERPOOL/ALAMY

DOGS living with other dogs often bark more than those in single-dog households when their owners leave home for a few hours – and they whine and howl just as much as dogs left alone.

The discovery suggests that getting a second dog might not be a reliable way to resolve the anxiety that some dogs experience when separated from their humans.

Gerrit Stephan at the Academy for Animal Naturopathy in Switzerland and his colleagues studied videos captured inside the homes of dog-owners to evaluate dogs' reactions when their humans left the house without them as part of their regular routine. They looked at footage of 32 dogs living alone and 45 dogs living with others.

During the first hour of separation, those in multi-dog homes typically showed a "striking" difference in activity compared with those in single-dog homes, with more walking around, barking, whining and howling, says Stephan. There was almost no dog-to-dog activity, like playing or licking each other (*Applied Animal Behaviour Science*, doi.org/g4s2).

"It's a common misconception – and often given as poor advice – that a dog with separation-related anxiety will fare better and show fewer stress responses if another dog is added to the household," says Natalie Waran at Eastern Institute of Technology in New Zealand, who wasn't involved in the project. "[But] this often results in another dog showing anxious behaviour."

Security

How Albert Einstein can help secure your bank account

Matthew Sparkes

ALBERT EINSTEIN'S special theory of relativity tells us that information cannot travel faster than the speed of light, an immutable fact of the universe that researchers now want to exploit to stop hackers from accessing your bank account.

When entering your PIN at an unfamiliar cash machine, you need to trust that its operator will protect this sensitive information and that someone hasn't interfered with the machine to steal your details. This need for trust is a weak link that security experts aim to eradicate.

One method of doing so is a zero-knowledge proof (ZKP), a mathematical concept that lets you verify your identity without actually sharing a PIN or password. One person, the prover, can show another, the verifier, that they have a certain piece of information without actually revealing it.

Since their invention in the 1980s, ZKPs have relied on mathematical functions. One example is the three-colour problem, where a map of thousands of areas is filled in with just three colours so that no two touching areas have the same colour.

It is highly computationally intensive to create such a map from scratch, so a prover could make one in advance to serve as their proof of identity, and the verifier could ask for the colours of two random areas that touch and check they are different. By repeatedly asking for pairs of random areas, with a short time between requests, the verifier can become increasingly confident that the prover has access to a properly coloured map, but never gets to see it.

A hacker without access to the original map could give random answers to the verifier, but with each additional check, the chances increase that their answers become inconsistent, revealing that they don't have the actual map.

Yet this, too, relies on an element of trust: you have to assume that someone with a secret supercomputer or publicly unknown algorithm isn't able to quickly create a map fast enough to trick the verifier.

Ideally, a ZKP would have the backing of an unchangeable constant of the universe, and now Sébastien Designolle at the University of Geneva in Switzerland and his colleagues have found a way to do this using Einstein's special theory of relativity. "You want to be as paranoid as possible and drop as many assumptions as possible," he says.

The team proposes having two provers that must each respond to one of two verifiers within a given time frame. The provers are placed too far apart to be able to confer on their responses, because even sending information at the speed of light would take too long. Once the provers have submitted their answers, the verifiers can confer and check they match, allowing them to spot any fake guesses.

In an experiment, the team used GPS clocks to synchronise two computers, serving as the provers, at a distance of 400 metres, which would take a signal travelling at the speed of light 1.3 microseconds to cover. Two verifying computers then each asked one of the proving computers to confirm the colour of two areas within 0.84 microseconds – less than the quickest possible conferring time between these computers. To establish with certainty that the proving computers weren't just making lucky guesses, the verifying computers made half a million requests (*Nature*, doi.org/g4v2).

Matthew Green at Johns Hopkins University in Maryland says the concept could provide a way to solve one of the fundamental problems with existing ZKPs: that you can attack them if you have computers that are powerful enough.

"What they're saying is there's a way around this, we can make proofs that are perfectly secure. No matter how much time you spend trying to break them, you won't break them," he says. "But the cost of that is you have to use this new model with two computers. The speed of light is what it is."

1.3

Time in microseconds it takes light to travel 400 metres

Entering your PIN at a cash machine requires trust

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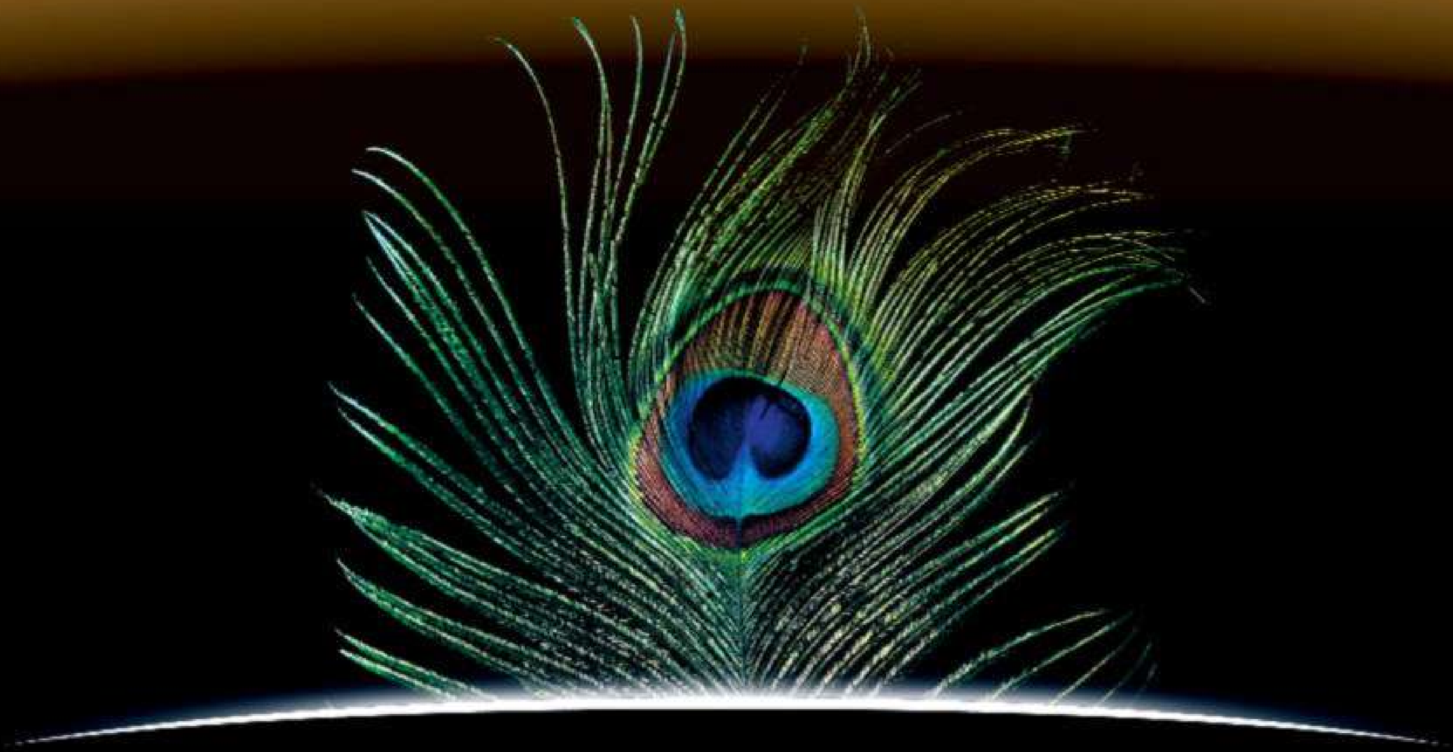

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[1] Source: Global Cement and Concrete Association

[2] Annual global cement production in 2019: 4.1 billion tonnes. Source: IEA.

[3] Precast industry is 30% of total. Sources: The Business Research Company & Fortune Business Insights.

[4] Typical passenger vehicle emits around 4.6 metric tonnes of CO_2 per year. Source: EPA.

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[1] IEA (2017), The Future of Trucks, IEA, Paris
[2] IEA (2020) CO_2 emissions from heavy-duty vehicles in the Sustainable Development Scenario, 2000–2030
[3] One young tree absorbs 5.9kg CO_2 per year. Source: Urban Forestry Network.

ROBIN UTRECHT/SHUTTERSTOCK

Environment

Target ammonia to help curb killer air pollution

REDUCING ammonia emissions may be a more cost-effective way to mitigate air pollution than focusing on nitrogen oxides alone.

Fine particulates that are less than 2.5 micrometres in diameter are formed when ammonia reacts with nitrous oxides (NOx) and sulphur dioxide. Known as PM2.5, these can get into the bloodstream and cause illnesses such as asthma, coronary heart disease and chronic obstructive pulmonary disease.

Baojing Gu at Zhejiang University in China and his team estimate that, in total, the pollution resulting from nitrogen emissions caused roughly 23.3 million years of lost life in 2013, with an economic cost of $420 billion.

They found that targeting ammonia emissions, the majority of which come from farming sources such as livestock production, would be a more cost-effective way to reduce PM2.5 pollution (*Science*, doi.org/g4v4).

Updating the way we produce meat, for example via changes to animal housing and diet, could help reduce ammonia emissions, since about 80 per cent come from agriculture, says Gu.

Most countries focus on reducing sulphur dioxide and nitrogen oxides to tackle fine particulate pollution. While ammonia reductions have been suggested in the European Union, most places have no policies on ammonia emissions.

"Globally, around 5 million people die each year due to [ambient] air pollution," says Gu. "We want to change policymaking to focus on not only NOx, but ammonia." **Krista Charles**

Marine biology

Giant whales have truly mighty appetite

BALEEN whales, the largest animals in the world, eat three times more prey than we thought. This implies they play a larger role in sustaining marine ecosystems than expected.

Matthew Savoca at Stanford University in California and his colleagues tracked 321 tagged baleen whales from seven species, including the humpback whale (*Megaptera novaeangliae*).

They followed these whales throughout the Atlantic, Pacific and Southern Ocean and estimated their feeding patterns using aerial photos of foraging areas and acoustic measurements of prey density, primarily crustaceans such as Antarctic krill (*Euphausia superba*).

The team found that the average amount of prey consumed per day by the seven species of whale was between 5 and 30 per cent of their body mass – a range that is three times higher than previous average estimates.

In the Southern Ocean, the team estimated that baleen whales ate around 430 million tonnes of krill per year before industrial whaling began in the early 20th century. This is twice the estimated mass of krill in our oceans today (*Nature*, doi.org/g4vz).

"This new higher estimate is important for the functioning of ocean ecosystems because whales act as giant nutrient recycling plants," says Savoca. "By consuming even more… they are also pooping more, and that poop is actually marine fertiliser." This fertiliser sparks the growth of marine plants, including phytoplankton, and provides food for krill and other small fish.

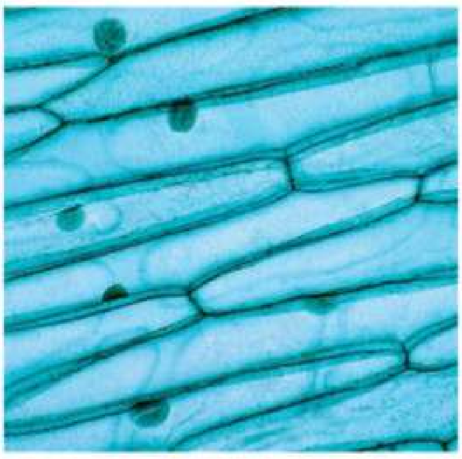
The study highlights how recovering whale populations can help to restore marine ecosystems. "It really is a true circle of life," says Emma Cavan at Imperial College London. **Chen Ly**

Materials

Fake plant-like cells could power robots

PLANTS may have no muscles, but their roots have the power to shift soil and rocks – because their cells can absorb water to form strong structures. Now an artificial material that mimics this ability could help to create better soft robots and medical implants.

Shelby Hutchens and her team at the University of Illinois at Urbana-Champaign formed so-called plant tissue analogues (PTAs) by fabricating closed cells from a compound of silicon called polydimethylsiloxane, which is semi-permeable like the walls of plant cells (pictured).



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They used varying salt levels in the cells to control how much water was absorbed through the polydimethylsiloxane walls. The more water absorbed, the stiffer and larger the cells became. This had to be tuned carefully, as at high salt concentrations the cells split.

The team found that if a layer of this material was bonded to a less expandable substance, the size increase of the PTA caused it to move and bend into an arched shape. This movement required no electrical power, only a source of moisture, and could be used to power soft robots or medical devices in the future.

Other materials exhibit expanding behaviour, but they lose stiffness as they swell. In contrast, the PTA strengthened as it took in water (*Matter*, doi.org/g4wn). **Matthew Sparkes**

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Really brief

PHOTOSHOT/AVALON.RED/ALAMY

Vampire bats may share gut microbes

Microbes could be transferred between vampire bats when they lick one another and share regurgitated food. This might explain why an analysis of bat faeces found that individuals living in the same colony share a similar gut microbiome (*Biology Letters*, doi.org/g4st).

CO_2 emissions up after 2020 drop

Global carbon dioxide emissions fell by 5.4 per cent in 2020 as a result of restrictions brought in to tackle the pandemic, but they may have risen by 4.9 per cent this year, according to the *Global Carbon Budget 2021* report published last week. This would put emissions back up to 2019 levels.

Global warming is raising tropopause

The tropopause, the boundary that lies between the troposphere – the atmosphere's lowest level – and the stratosphere, increased in altitude over the northern hemisphere at a rate of about 53 metres per decade between 2000 and 2020. This is because of climate change (*Science Advances*, doi.org/g46c).

Allergies

Infant peanut advice failing to get through

LESS than half of US children are given peanuts to eat in the first 11 months of life, even though an early introduction lowers the risk of developing allergies to them.

The finding comes from Ruchi Gupta at Northwestern University in Illinois and her team, who surveyed a representative sample of more than 3000 homes with children aged 7 months to 3.5 years.

"High allergy risk children who eat peanuts early in life are five times less likely to develop a peanut allergy," says Carina Venter at the University of Colorado in Denver, a co-author of the study. That finding, in a 2015 study, led to a swift change in US guidelines on the early introduction of peanuts.

Parents had long avoided giving peanuts for fear of making their children allergic, and official advice was unclear. But in 2017, the US National Institute of Allergy and Infectious Diseases recommended that high allergy risk children in the US be given peanuts between 4 and 6 months of age, while other children should get peanuts "freely" and early in their lives.

However, the new analysis found that only 58 per cent of participants said their doctors had advised them about the benefits of early peanut introduction. Only 40 per cent of these respondents said that their doctors had told them to introduce peanuts to their child while aged less than a year.

Just 44.7 per cent of participants reported giving their children peanuts early on. The work was presented at the American College of Allergy, Asthma & Immunology meeting on 5 November.
Jason Arunn Murugesu

Health

CHICCODODIFC/SHUTTERSTOCK

Time spent exercising shows no link to arthritis of the knee

THERE seems to be no link between the amount of exercise people do and whether they develop painful osteoarthritis in their knees.

Previous studies have found conflicting results on whether exercise can make arthritis more likely. So Lucy Gates at the University of Southampton in the UK and her team combined six such investigations, involving over 5000 people who initially had no knee pain or other evidence of arthritis.

These people recorded average time spent exercising, while their activities were graded by metabolic equivalent, or MET, scores, a way of classifying how much an activity raises a person's metabolic rate.

At the end of the studies, which lasted from five to 12 years, people were asked if they had developed frequent knee pain or if arthritis had been diagnosed by a scan.

The analysis shows the chance of developing arthritis didn't correlate with activity level, either by time spent exercising or by combined time and MET scores (*Arthritis & Rheumatology*, doi.org/g4v6).

However, it remains possible that some forms of exercise might raise the risk. "There's more work to be done on disaggregating risk and different types of activity," says Gates. **Clare Wilson**

Animal behaviour

Spiders woo mates with scented gifts

MALE nursery web spiders persuade females to mate by wrapping food in silk laced with attractive chemicals.

Gift-giving is a part of courtship among nursery web spiders (*Pisaura mirabilis*). To find out more, Michelle Beyer and her team at Ludwig Maximilian University of Munich in Germany gave dead houseflies to male spiders and allowed them to wrap the prey.

The researchers then either unwrapped the fly before putting the silk in ethanol and water to remove any chemicals and then re-wrapping a fresh fly in it, or left the gifts untouched. Unwrapped dead flies were used as a control.

The researchers used tongs to offer the food gifts to 35 female spiders and found that unwashed gifts were accepted around 75 per cent of the time and washed gifts around 40 per cent of the time, suggesting that molecules on the unwashed silk swayed the females towards gift acceptance – exactly which substances is unclear. The unwrapped control gifts were only accepted around half the time (*Biology Letters*, doi.org/g4wq).

It is possible that the chemicals require a lot of energy to produce, so signal a healthy male to a mate, says Beyer. **Carissa Wong**

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Comment

Prejudged prescriptions

Relying on race and ethnicity when interpreting medical test results can harm patients. It must stop, say **Layal Liverpool** and **Jennifer Tsai**

SHOULD your race or ethnicity influence the prescription you get from your doctor? Both are still used in medicine to interpret test results and guide treatment decisions, but the evidence is questionable and the approach can cause serious harm.

Medical guidelines in the US, UK and elsewhere often recommend the use of algorithms that contain adjustments for a person's race or ethnicity, from tools used to assess bone fracture risk to devices containing embedded racial or ethnic adjustments for measuring lung function. The latter can be partly traced back to the suggestion by US slaveholder Samuel Cartwright in the 1800s that Black people had naturally low lung capacity and so were healthier when enslaved.

These algorithms are finally coming under significant scrutiny. Recently, the US National Kidney Foundation and the American Society of Nephrology formally established a consensus against the use of race adjustment in kidney function equations. A similar race-based kidney test adjustment was also removed from UK medical guidance set by the National Institute for Health and Care Excellence (NICE). These decisions came in response to growing concerns that the race adjustment was contributing to underdiagnosis and undertreatment of kidney disease among Black people.

ROBERTO CIGNA

Yet race-based decisions are still permeating other parts of medicine with little evidence to support them. NICE, for example, has declined to review its guidance on high blood pressure treatment that recommends different drugs for Black people compared with everyone else. The guidance currently says that doctors should prescribe drugs called ACE-inhibitors to people under the age of 55 with high blood pressure – unless they are of "black African or African-Caribbean family origin", in which case they should receive different drugs.

Dipesh Gopal, a general practitioner who is also at Queen Mary University of London, and his colleagues have written to NICE twice over the past year requesting an urgent review of this guidance, but it declined in both cases, responding that evidence suggests there are "clinically meaningful differences in the effectiveness of treatments for individuals in these family origin subgroups".

But Gopal and others dispute this evidence, particularly given that race and ethnicity are poorly defined social constructs with no biological basis. Indeed, according to the data, people's treatment responses quite literally aren't black and white.

In response to Gopal and his colleagues, and to the content of this article, NICE said that "there is not a clear-cut biological and genetic homogeneity amongst all Black and White people" and that "the guideline does not account for people with mixed heritage". But it said performing the relevant tests on everyone wasn't possible due to "the expense, and the additional time".

Using race or ethnicity as an indicator of biology in this way is lazy and imprecise. NICE and other health organisations globally should start systematic reviews of race-based recommendations across their guidelines immediately. A doctor's glancing assumption about a person's race or ethnicity doesn't offer meaningful biological information that can guide medical decisions. They aren't biological variables and can't be used as a proxy for genetic make-up.

This doesn't mean medicine should become colour blind. Racism clearly drives health inequities in many countries and this must be addressed. But perpetuating harmful and unscientific ideas about biological differences between races in medical guidance isn't the solution. ■

Layal Liverpool is a science writer based in Berlin and Jennifer Tsai is a physician and writer based in Connecticut

Field notes from space-time

The fourth neutrino There are reasons to think the neutrinos we know have a shy cousin that could explain dark matter, but it won't be easy to spot, writes **Chanda Prescod-Weinstein**

Chanda Prescod-Weinstein is an assistant professor of physics and astronomy, and a core faculty member in women's studies at the University of New Hampshire. Her research in theoretical physics focuses on cosmology, neutron stars and particles beyond the standard model

Chanda's week

What I'm reading

I got an advance copy of the new comic book LUNAR ROOM #1, *and it is excellent.*

What I'm watching

I am very excited that Succession *is back!*

What I'm working on

We are into letters of recommendation and grant proposal season here, so I'm doing a lot of both.

This column appears monthly. Up next week: Graham Lawton

YOU might have seen recent headlines about a "sterile neutrino" and been confused. Regular readers know that I am a fan of neutrinos, in part because they are non-trinary: they come in three flavours and randomly switch between them for reasons we have yet to fully explain. The kinds of neutrinos I have discussed in this column before are those we have detected: electron neutrinos, muon neutrinos and tau neutrinos.

These three flavours are fundamental particles in the standard model of particle physics, our best picture of matter and its interactions. They are members of the lepton family along with electrons, muons and taus. Like their leptonic kin, the standard model neutrinos are in a class of particles called fermions, defined by having an internal quantum sense of rotation – spin – that is a multiple of a half. Importantly, these neutrinos interact with other particles through gravity and the weak nuclear force.

Sterile neutrinos are, as we say in the US, a whole new ball game. Unlike standard model neutrinos, we don't know if they are real. And unlike the neutrinos we know, they seem to only interact through gravity. Sounds boring, you might think. Why bother? First of all, everybody knows that I like a good dark matter candidate. I am especially fond of one that I can argue should exist anyway, regardless of our missing, invisible matter problem. Sterile neutrinos share two of my favourite qualities for a hypothetical particle: they are well-motivated and they happen to be interesting dark matter candidates.

We think sterile neutrinos should exist thanks to a property of standard model neutrinos: handedness. Specifically, the neutrinos we know are lefties (and antimatter antineutrinos are all righties). Though I am referring to this as handedness, this property – formally known as chirality – isn't quite like everyday life because it isn't classical. Like particle spin, it is a quantum feature.

Every known particle can come in both left and right-handed forms – apart from neutrinos. They come only as left-handed particles. Naturally, over the years, physicists have wondered whether there are right-handed neutrinos (and left-handed antineutrinos).

The sterile neutrino is that hypothetical right-handed neutrino. It is named "sterile" because it only interacts through gravity. While this property makes sterile neutrinos different from other neutrinos, they do have a mass and aren't electrically charged, just like standard model neutrinos. This means they could be dark matter and, unlike standard model neutrinos, they potentially have sufficient mass to explain the apparent gravitational impact of dark matter's presence.

> "Detecting ordinary neutrinos is difficult enough. That work is even more complicated with sterile neutrinos"

Those of us who are theorists get the exciting work of figuring out how the idea that sterile neutrinos could be dark matter would work mathematically. Experimentalists get the joy – and incredible challenge – of going out and looking for physical evidence.

One of these searches recently caused some headlines by finding a null result: no sterile neutrinos. Detecting ordinary neutrinos is difficult enough. That work is even more complicated with sterile neutrinos, which can only be "seen" through their interactions with quantum fluctuations of their standard model counterparts. To find sterile neutrinos, you have to look for a specific type of behaviour in everyday neutrinos.

The experiment that recently announced results, MicroBooNE, is located at Fermilab, not far from Chicago. It consists of a large container of argon attached to a beamline where neutrinos are produced by colliding protons together. It is easier to follow the trajectory of neutrino events in argon, due to its high density and sensitivity to the charged particles that are produced in the collisions.

MicroBooNE's primary task is to better understand how neutrinos interact with argon and to try to replicate the hints seen in earlier experiments that sterile neutrinos are real. Two experiments, MiniBooNE and LSND, saw an excess of muon neutrinos oscillating into electron neutrinos over distances that didn't physically make sense. This oddity could be explained if the muon neutrinos were first becoming sterile neutrinos, before changing into electron neutrinos.

Sadly for some, the MicroBooNE team announced recently that it hadn't, so far, seen the same electron neutrino excess. This is consistent with data from other experiments, leaving us with quite the mystery. Why are different experiments getting different results? We don't know.

But even if nothing turns up once we have explored every place this hypothetical particle could be hiding, that will still be valuable. If sterile neutrinos turn out to only be a figment of the particle theorist's imagination, we will know it is time to move on. ■

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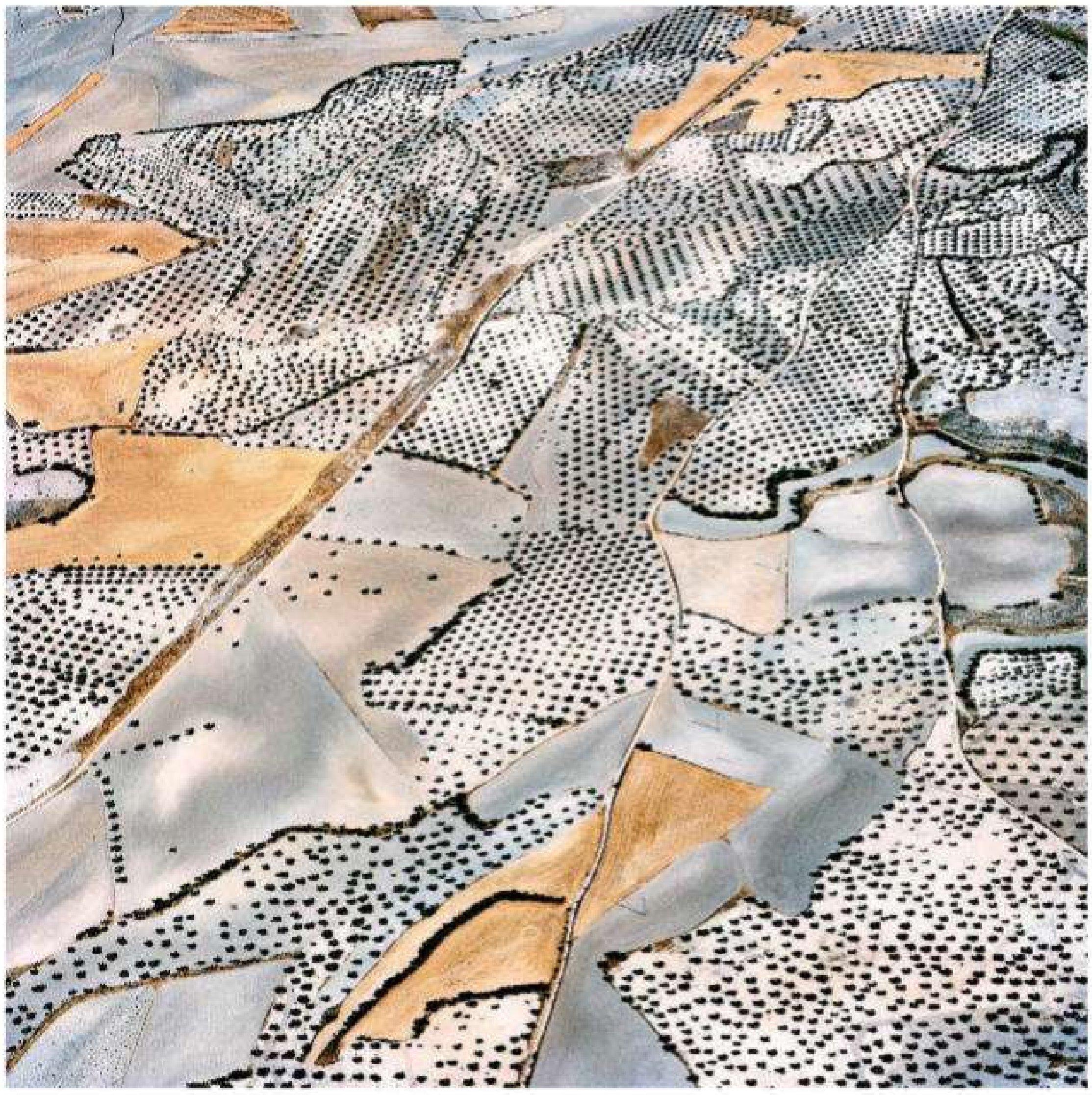

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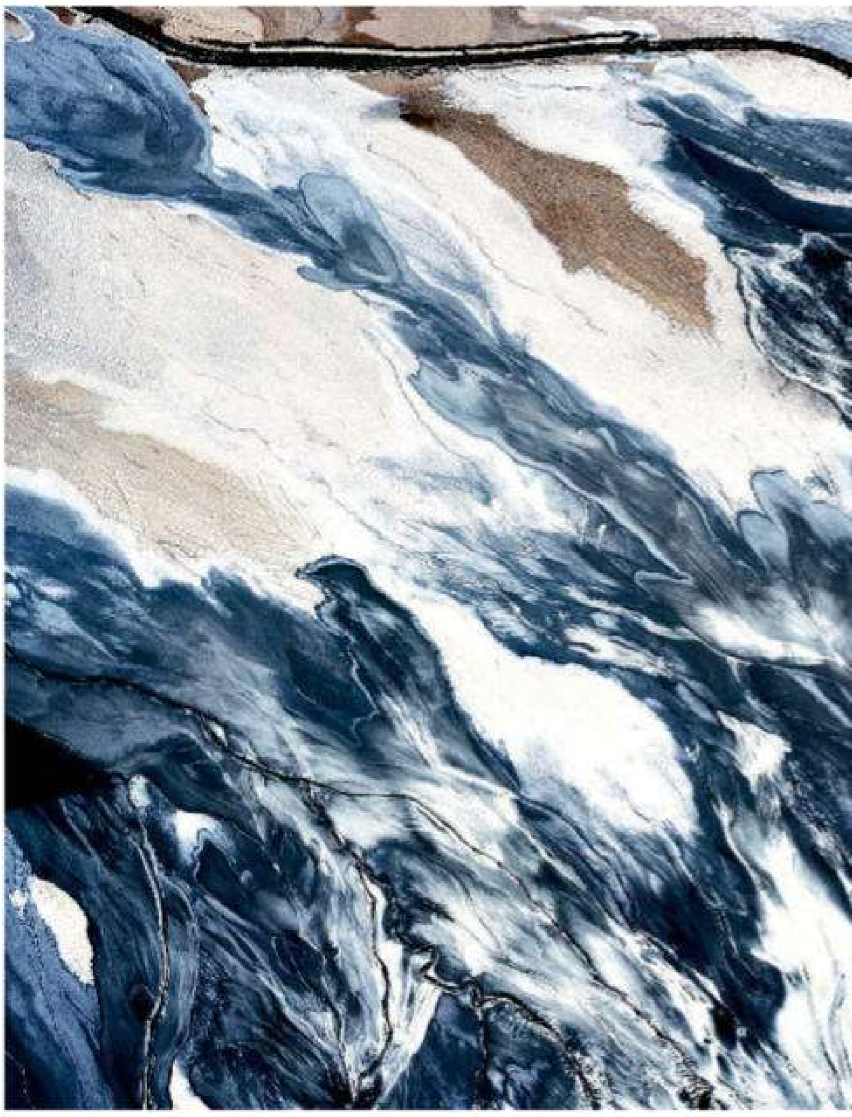
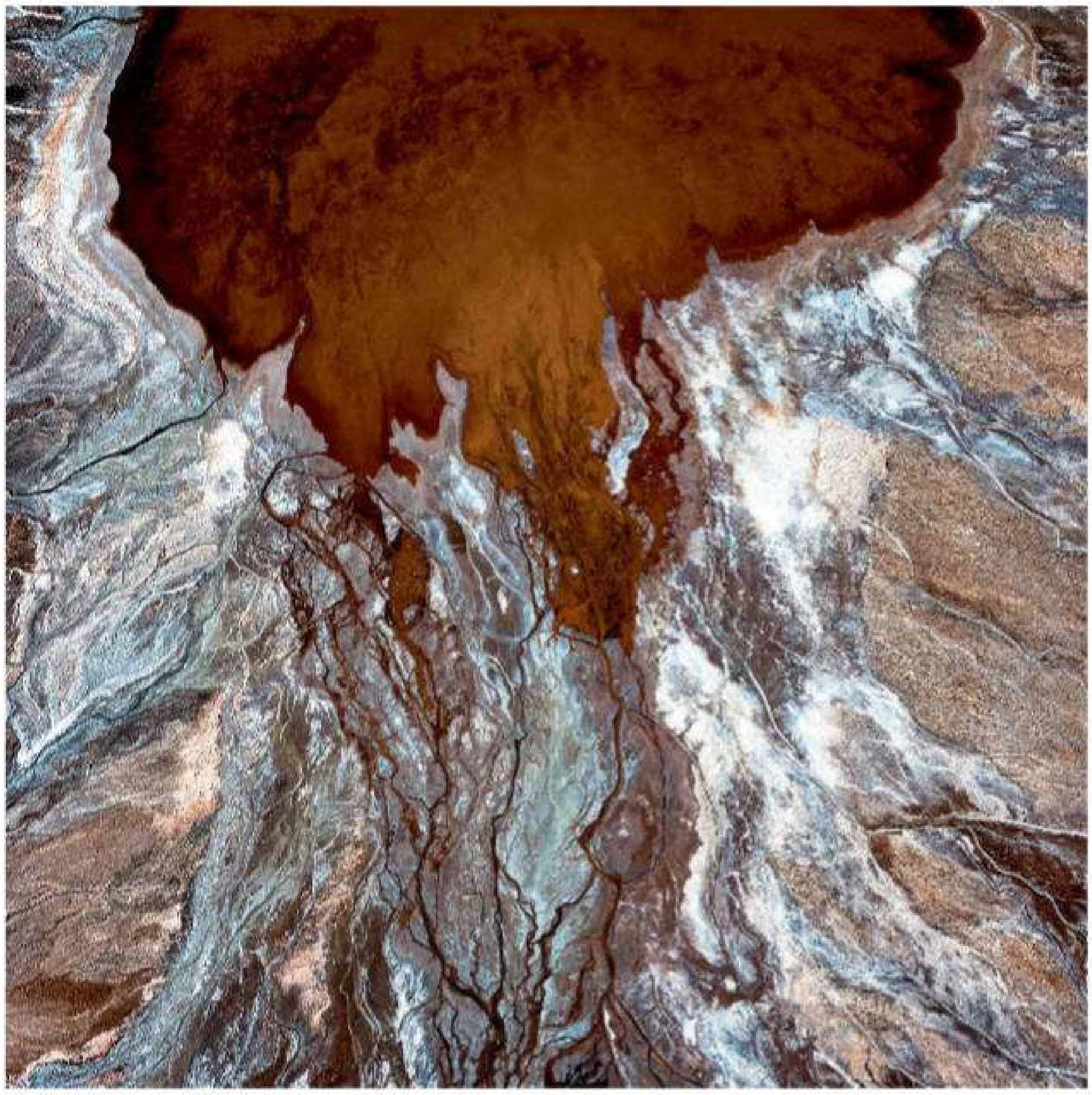
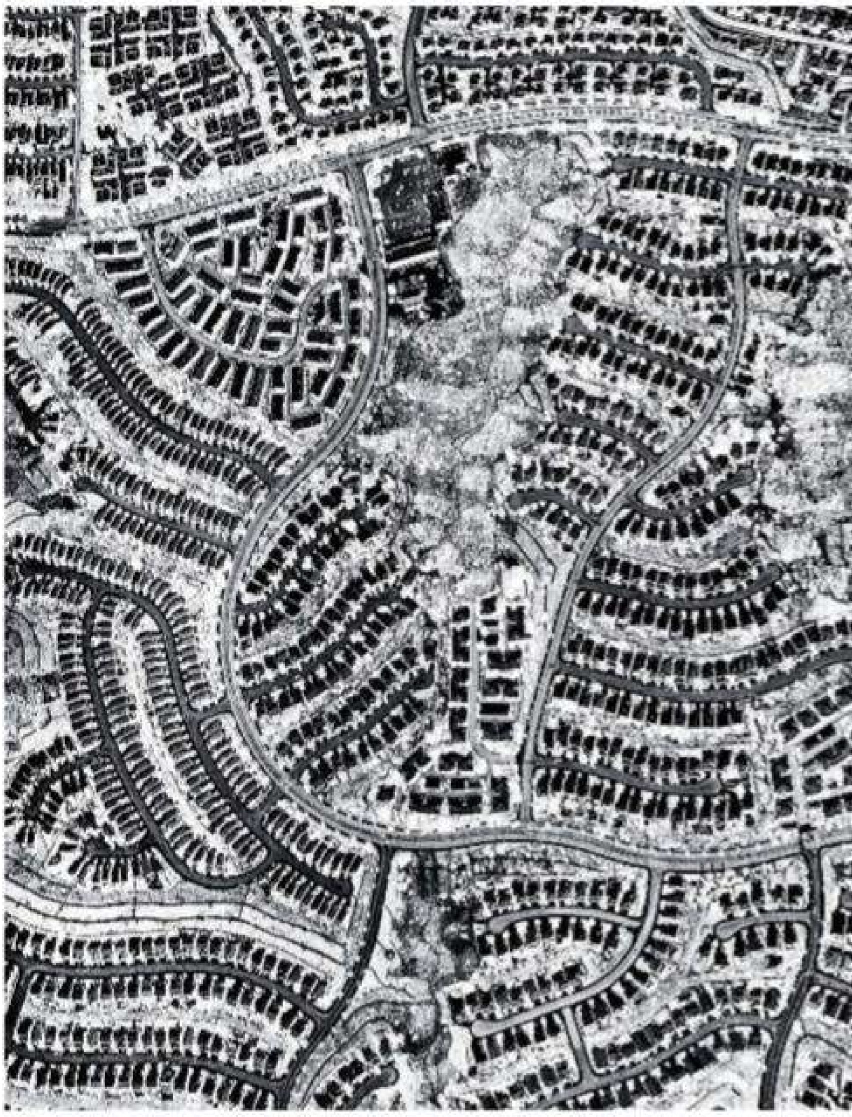


DESOLATION DESERT, TAILINGS POND 4, MINERA CENTINELA COPPER MINE, ANTOFAGASTA REGION, ATACAMA, CHILE, 2018



DESOLATION DESERT, TAILINGS POND 14, VICINITY OF PEDRO DE VALDIVIA, ATACAMA, CHILE, 2018



OBLIVION 3N, 2004

OBLIVION 21N, 2004

THE MINING PROJECT (CLIFTON, AZ 1), 1989

Impact writ large

Photographer David Maisel

THESE dazzling shots of transformed landscapes paint a stark picture of our effect on the world, and what we leave behind. They are part of artist and photographer David Maisel's latest exhibition, The Expanded Field.

Over three decades, Maisel took aerial photos of environmental change and human activity, such as desertification zones and mining projects, to reveal the scale and dramatic consequences of our actions.

The top-left image is taken from Maisel's photo series *The Fall*, which features regions near the Spanish city of Toledo. This 2013 shot reveals the grey of La Mancha agricultural plateau, which results from the mineral borax in the soil.

Another of Maisel's series is *Desolation Desert*, which features mines in Chile. The 2018 photo at top centre shows one of the Minera Centinela copper mine's tailing ponds, dammed to hold the toxic by-products of mining. A further tailing pond, in the vicinity of a former nitrate-mining area, Pedro de Valdivia, can be seen in the image at bottom left, also taken in 2018.

The modernity and sprawl of Los Angeles is captured in the top-right and bottom-centre images, taken in 2004 and drawn from Maisel's *Oblivion* series.

The bottom-right image, taken in 1989 and part of Maisel's *The Mining Project* collection, shows surface water contaminated by the products of a gold-mining project in Clifton, Arizona.

The Expanded Field is at the Edwynn Houk Gallery in New York City until 20 November. ▮

Gege Li

For more on the environmental impact of mining, see page 38

Editor's pick

Biting back over the vegan substitutes health trap

30 October, p 38

From David Aldred, Elloughton, East Yorkshire, UK

Veganism isn't about human health, it is about animal health: if you don't breed, enslave, slaughter, skin and eat animals, they tend to stay healthier. Your article never mentions that veganism isn't just about food, but also clothes, make-up, hair products, pharmaceuticals, ceramics, weapons and pretty much everything else.

Better human health would be a pleasant by-product of veganism, but it is by no means the goal. Maybe you are confusing the philosophy of veganism with what adherents call "plant-based diets", which are all about human health.

From Eric Kvaalen, Les Essarts-le-Roi, France

Your article on vegan substitutes draws on flaws in dietary science that were pointed out in an article you published two years ago (13 July 2019). This showed how most dietary advice is based on observational studies rather than randomised, controlled studies, a state of affairs that leads to contradictory guidance on things like salt, sugar and fat.

You cite more observational studies about "ultra-processed foods", which of course have the same weaknesses explained in your earlier article. I suspect the real reason for the adverse effects of vegan substitutes is that people like them and so eat too much.

The climate crisis is just a tragedy of the commons

30 October, p 8

From Tim Stevenson, Prestwood, Buckinghamshire, UK

One phrase that doesn't seem to be used enough in the context of the COP26 summit and climate change is "the tragedy of the commons". This describes a scenario that is a standard part of mathematical game theory.

The "tragedy" considers free public use of a common resource – for example, community-owned land for grazing cattle. In that case, the community's interest is best served by controlling use to the level that optimises grass growth. However, each individual cow owner does best if they maximise the amount their cattle eat. Their loss because of the degradation due to their minor contribution to overgrazing is swamped by the extra resources they gain.

The only solution to this is collective management of usage. The trouble with climate change is that the world has no mechanisms for truly effective collective control.

From Hillary Shaw, Newport, Shropshire, UK

Having read several pages on COP26 and the need to cut emissions, I was struck by the irony of a story on the next page reporting advances in restoring male fertility (p 13). The largest contribution an individual can make to reducing carbon emissions is to not have a child.

Rooting for Finland's tree-based circular economy

30 October, p 21

From Trevor Jones, Sheringham, Norfolk, UK

Graham Lawton's article "A wooden circular economy", on Finland's research and development of a cyclical symbiosis of woodlands, forestry and wood technology, was life-affirming and full of hope for the future. Finland demonstrates one way forward that embraces the beginning of a new age of wood and the coming of sustainably sourced timber to reduce carbon emissions and the destruction of Earth's primordial ecosystem.

How to make heat pumps more attractive

23 October, p 9

From Christopher Jessop, Marloes, Pembrokeshire, UK, and Andrew Gigiel, Bridgwater, Somerset, UK

Coupled with insulation and draughtproofing, heat pumps are very good for warming buildings sustainably, but they cost more than boilers and are more complicated. While reliability is excellent, repairs by skilled technicians (if needed) are costly. And knowing how to run a heat pump optimally is difficult when some power tariffs alter the price of electricity every half an hour.

Our solution, laid out in our Institute of Refrigeration paper "Why don't people install heat pumps?", is to lease a heat pump, not buy one. This keeps the supplier responsible for maintenance, repair and end-of-life replacement. As with district heating, householders should pay the heat pump provider a price per unit of heat delivered, letting them source the electricity.

Horse origin may shed light on a bigger mystery

30 October, p 18

From Peter Mullins, Haworth, West Yorkshire, UK

Your article on the possible origin of domesticated horses has some important wider implications. These relate to the realisation that languages as diverse as modern Welsh and classical Sanskrit have a common root, which has led to a search for the origins of a Proto-Indo-European language.

There are strong suggestions that it was spoken in an area north of the Black Sea and Caspian Sea at least 5000 years ago. Yet there is no genetic trace or historical record of a conquering or trading people from this area back then, so speculation about their mobility, spread and cultural dominance has involved everything from their having invented the wheel to their domestication of horses.

Your report that DNA analysis shows the first domesticated horses were present in this area at this time is therefore very striking.

Issue of Indigenous land in the US runs very deep

2 October, p 26

From Lucy Roberts, Wantage, Oxfordshire, UK

Regarding Annalee Newitz's look at the truth behind land used to fund some universities in the US – that is to say, the fact that it was taken from Indigenous people. My understanding is that pretty much all land in the US was stolen from these people, either by fake treaties, massacres, forced deportations and/or disease – sometimes spread accidentally, sometimes deliberately.

It is great that some universities are trying to make reparations for this, but what about the owners of the rest of the land?

Turn your food waste into a tasty 'rubbish soup'

25 September, p 42

From Silvia Dingwall, Nussbaumen, Switzerland

When it comes to reducing food waste, we often put vegetable peelings in a pressure cooker (a great energy-saving device) with some water, herbs and garlic to make a healthy vegetable broth we call "rubbish soup".

We keep the strained liquid and put any remaining solids in the compost, working on the principle of "use as much as you can before you bin it". Perhaps readers have other creative ideas or recipes. ■

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A sticky subject

Surfaces rarely get a second thought, but a new book explains the fascinating science behind them, writes **Gege Li**

Book
Sticky: The secret science of surfaces
Laurie Winkless
Bloomsbury

PAUL D STEWART/NATURE PICTURE LIBRARY/SCIENCE PHOTO LIBRARY

Geckos' sticky feet have confused and inspired generations of scientists

WATCHING paint dry isn't normally a very exciting affair. But it turns out there is more happening at the surface – and indeed all surfaces – than meets the eye. Understanding what is going on there might help us improve how we design and engineer technologies and unravel key scientific questions.

At least, that is what Laurie Winkless says in her new book *Sticky: The secret science of surfaces*. It is a revealing look at the forces at play when materials come into contact, and the experiments and innovations that have come about from studying these interactions in both natural and artificial settings.

The book starts out by debunking the very terms that we might think of when two things meet: stickiness or slipperiness. There are no definitions or ways to measure how sticky or slippery something is, writes Winkless.

When it comes to stickiness, the interactions that are happening at the point where one surface meets another – be it air, water or some other medium – are what matters. To make a good can of paint, for example, it is all about the chemical reactions, from how the pigments and binders mix to the way the paint dries in the air.

With drying, getting the pigment to stay on the surface once the water evaporates is a challenge. Careful considerations that draw on fundamental particle science – including the interactions between hydrophilic pigments and hydrophobic molecules – are key to making paint stick just right as it dries.

At the heart of most surface interactions is friction, the force that resists motion when surfaces slide against each other, holding objects in place or slowing them down. One example of friction's power that Winkless explores is the gecko, an animal that has puzzled and fascinated researchers for decades. Known for the remarkable sticking and unsticking ability of its feet, the gecko can grip and move with ease over most surfaces, even ones that are inverted or slippery.

Studies have now revealed that this is thanks to tiny hairs covering the gecko's toes. The stickiness is "switched on" by small electrostatic forces forming between the foot and the surface, then "switched off" simply by angling the foot differently.

The gecko's ultra-sticky feet – "the smartest on-off adhesive in the world", says Winkless – are so impressive that they have inspired robots that can scale surfaces and adhesive hand pads that allow humans to climb glass walls. "We can create, build, join, enhance and beautify objects through clever design and chemistry," writes Winkless. "To my mind, there's no doubt that surface science shapes our world."

Even so, contact between surfaces may not be entirely what it seems – since even dry surfaces probably have a film of water between them, and many are rough and uneven. This means we need to zoom in if we are to learn what is really going on, says Winkless. To do this, she looks at how things make contact at the atomic level, exploring nanoscale technologies used in welding and lubricants, and microscopic tools for measuring friction.

> **"Despite the astonishing complexity of surfaces, we have somehow learned to navigate and control them"**

Friction is perhaps the biggest enigma of all. We still haven't figured out how to bridge the gap between friction on the atomic scale and larger, more classical systems, such as engines. If we could figure this out, it would be "transformative", writes Winkless, and may help with everything from building nanorobots to designing precision instruments.

But she is optimistic that our current knowledge isn't going to hold us back. "Despite the astonishing complexity of the science of surfaces, we have somehow learned to navigate, and in many cases, control it… to focus solely on what we don't know would be doing a disservice to what we do know," she writes.

On that front, *Sticky* certainly works as a comprehensive introduction to surfaces, or the "world that hides in plain sight", as Winkless puts it. She draws on a multitude of work to make a solid case that there is much to learn from casting our focus on these interfaces – maybe even enough to convince you that watching paint dry isn't boring after all. ▮

Gege Li is a writer based in London

Tales from the future

An exciting collection of short stories covers a lot of interesting ground, finds **Robyn Chowdhury**

Book
Cosmogramma
Courttia Newland
Canongate

COURTTIA NEWLAND's *Cosmogramma* is one eclectic mix of tales. The anthology jumps between thrillers, sci-fi and cosmic horror to tell stories from a world with robot armies, circuses of cyborgs and mysterious, other-worldly happenings.

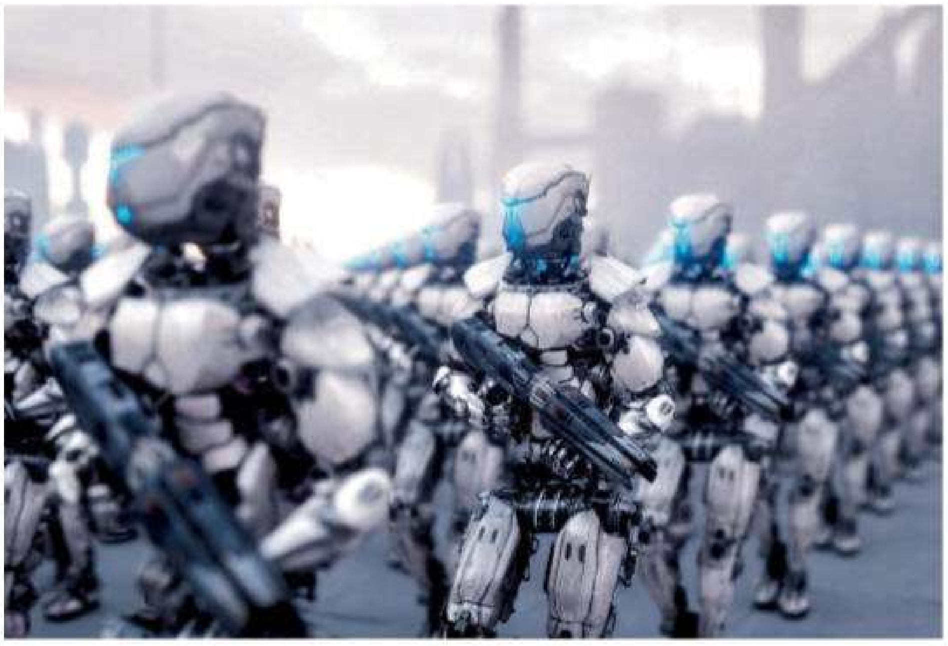
This is Newland's second work of speculative fiction, having released his first – *A River Called Time*, which featured parallel versions of London – earlier this year. The book begins with "Percepi", a story about companion robots that end up forming their own armies. Androids and humans alike are forced to choose between siding with the rebels and the government that wants to get rid of them. In an interesting twist, we learn that the androids can feel pain, just like the people fighting alongside them.

Stories across the collection are united by Newland's talent for depicting a world shaped by, and through the eyes of, the African diaspora. In "Nomma", for example, he draws on Malian folklore to create an incredibly moving and engaging story about undersea beings and their quest for survival.

The couple at the centre of it, Ray and Fari, are lured to an underwater palace and asked to join a society descended from ancient aliens. They are given just days to decide whether to stay on land or to live away from the rest of human society. The problem is that they must make their decision together, and the ensuing disagreement reveals cracks in their relationship.

Another story, "You Meets You", is about personal growth through addiction. Written in the second person, when we, as the main character, meet the younger and older versions of ourselves, we are forced to examine the way that we live, our addictions and our traumas. Each version of us has a story to tell, and we see first-hand what we will become if we don't get help.

Several of the pieces in *Cosmogramma* have an intense emotional element, asking questions about what people would do for their families, loved ones and other people in a dystopian future.



The futuristic world of *Cosmogramma* features android armies at war with humans

PAVEL CHAGOCHKIN/SHUTTERSTOCK

Across the collection, the fiction element of science fiction is most effective – but in "The Sankofa Principle", genuine science creates a backdrop for a futuristic landscape. Newland mentions notable scientific events – such as the detection of gravitational waves by the Laser Interferometer Gravitational-Wave Observatory in 2015, and the idea that black holes may create wormholes – to help create a reality where time travel is possible.

Politics is a common theme throughout the anthology, with some stories explicitly mentioning political events like Brexit or depicting the horrors of anti-immigration raids. This form of realism has been one of the most notable features of Newland's writing since his first novel, which depicted experiences of being Black in London, was published in 1997.

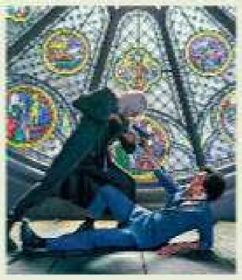
Overall, the combination of excellent world and character building and the rising intensity of each story as the book progresses means *Cosmogramma* is hard to put down. Stories feel almost unfinished, often leaving the reader on highly emotional cliffhangers, but this is one of the best things about Newland's storytelling.

The unfinished feel gave me time to consider what exactly might happen next in a world I was introduced to just 10 pages prior, and kept me engaged and in suspense for the majority of the anthology.

***Cosmogramma* is a collection that you will want to read again and again, both to better understand the complex storylines and to simply enjoy the African-futuristic worlds that Newland has created.** ▮

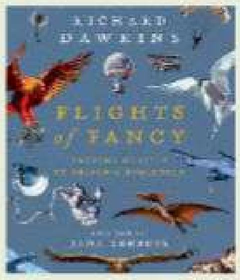
Robyn Chowdhury is a freelance writer based in Sheffield, UK

Don't miss



Watch

Cowboy Bebop finds Spike Spiegel (John Cho), Faye Valentine (Daniella Pineda) and Jet Black (Mustafa Shakir) trying to outrun their past in a live-action version of the notorious anime space western. On Netflix from 19 November.



Read

Flights of Fancy, beautifully illustrated by Jana Lenzová, is the latest book by Richard Dawkins in which he explains how living things took to the sky and inspired humans to extraordinary feats of their own.

Watch

A Nightwatchman's Journey is undertaken by writer and discoverer of comets David Levy, pictured, whose talk streams on the Astronomical Society of Edinburgh's YouTube channel at 7.30pm GMT on 19 November.

TOP: GEOFFREY SHORT/NETFLIX; BOTTOM: DAVID LEVY

A world of waste

A new exhibition showcases how much waste humans are responsible for and what we can do to stop the flood, finds **Graham Lawton**

FELIX SPELLER

This is a VW Beetle, when broken into the materials it is made from

Exhibition

Waste Age: What can design do?

Design Museum, London

Until 20 February 2022

ONE of the most striking displays in the timely and eye-opening exhibition Waste Age is an array of 41 cubic and rectangular blocks made of various materials, including steel, rubber, glass, chromium, graphite, horsehair, plastics, oil and brake fluid. The last two hold clues as to the origin of the materials: they all used to be a Volkswagen Beetle that has been broken down into its constituent substances. It is the product of an art project called Materialism that deconstructs everyday objects from pencils to smartphones in order to lay bare how much we rely on materials extracted from the planet.

The despoliation of Earth is a recurring theme in Waste Age, which opened at the Design Museum in London on the eve of the crucial COP26 climate talks in Glasgow, UK. The goal is to hammer home the environmental costs of our linear economic model and showcase the possibilities of a circular one, where products and materials are endlessly reused and recycled, rather than dumped or discarded.

The exhibition especially focuses on the underappreciated role designers play in delivering the transition to a less wasteful, or preferably zero waste, economy. "Eighty per cent of the environmental impact of the things around us is decided at the design stage, in what materials designers choose," says co-curator Gemma Curtin. "We should think of waste as a resource. Some designers are really grasping that and running with it."

The opening part of the exhibition is an exercise in clobbering us into submission with big numbers. We have, it says, reached "peak waste". The world produces 2 billion tonnes of waste every year, more than seven times the combined body weight of everyone alive. Around half of this is food and other biological materials, but the rest is glass, metal, clothing, plastic, paper, construction materials and electronic waste. An average European discards 11 kilograms of textiles a year – 87 per cent ends up in landfill or incinerators.

> "An average European discards 11 kilograms of textiles a year – 87 per cent ends up in landfill or incinerators"

Judging from the exhibits, the circular economy will be more than capable of delivering material comfort and elegance. Among other things, there is an array of trainers and designer dresses created from plastic rubbish, beautiful new materials made from agricultural and aquacultural waste, furniture created from corn husks, insulation made from fungi, and laptops and smartphones that can be totally dismantled into their component parts to be repaired, upgraded or recycled. Almost everything we casually toss aside can be recycled into products that are, in the words of 19th-century designer William Morris, either useful or beautiful. Or both.

Fixing stuff looms large, with a section on the growing right-to-repair movement, whose manifesto declares "if you can't fix it, you don't own it". Its goal is to make as many products as possible repairable rather than disposable, to save money, resources and the planet.

Earlier this year, France became the first European nation to bring in a repairability index. By law, five categories of electronic product – smartphones, laptops, washing machines, televisions and lawnmowers – must carry information, a bit like an energy-rating label, on how repairable they are. More product categories will be added in the next few years.

If the intended effect of the exhibition is to open our eyes to the wastefulness of the throwaway economy and the possibilities of the circular one, it works. I dare say most people will enter with a linear economy mindset and leave with a circular one.

Curtin says that as a result of curating this important exhibition, she sometimes envisages her own personal landfill – and it isn't a pretty thought. "The concept of throwing something away is just wrong," she says. "There is no away." ▮

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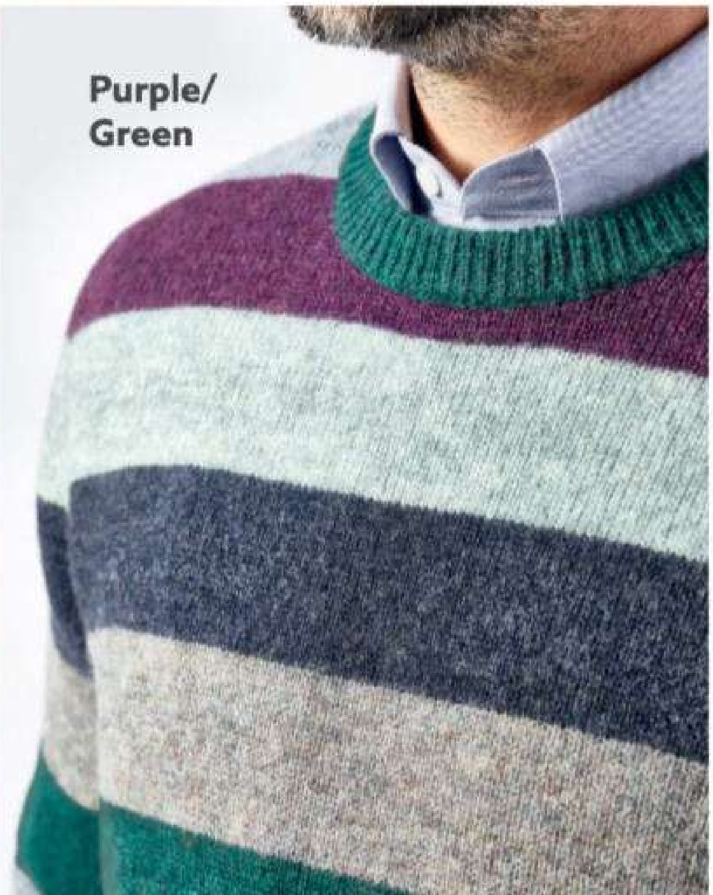

Net zero's dirty secret

Batteries, wind turbines, solar panels and other clean energy technologies require more minerals to be extracted from the ground. Can that ever be green, asks **Graham Lawton**

IF THE unofficial rallying cry of the fossil fuel lobby is "drill, baby, drill", renewable energy should have one too: "dig, baby, dig". If we are going to hit our climate targets, the world is going to need a lot of new mines.

"Minerals are essential ingredients of the future clean energy system," says Fatih Birol, executive director of the International Energy Agency (IEA). "If we try to visualise our future clean energy systems – millions of electric vehicles, cars, buses, windmills, solar panels – they need minerals to build. Huge amounts of minerals."

He isn't exaggerating. According to a recent IEA report, if the world is to reach its target of net-zero carbon emissions by 2050, overall demand for what it calls "critical minerals" – including lithium, copper, cobalt, nickel and the rare earth elements, all of them vital ingredients of clean energy tech – will increase sixfold. Another recent estimate from Japan's National Institute for Environmental Studies forecasts that electrifying transport and expanding renewable power generation will increase demand for minerals about seven times by 2050.

That presents a huge challenge to the realisation of our clean energy dreams. While there is no shortage of the minerals themselves, getting them out of the ground in time, in sufficient quantities, and without creating another environmental monster, is a different matter. Ultimately, we have no choice. "We need to do it," says Kingsmill Bond, a strategist at energy think tank Carbon Tracker. "But we need to do it the very best way we can, so that we don't trash the planet again."

Mining is already a blot on Earth's landscape, albeit a necessary one. According to Rich Crane at the Camborne School of Mines in Cornwall, UK, even though mining technology has

Lithium is crucial for batteries, and Bolivia's Salar de Uyuni has the largest known deposits

KSENIYA RAGOZINA/ALAMY

improved immeasurably over the course of human history, 99 per cent of all metal mining still relies on the process of physically extracting solid ores, often after removing vast amounts of overlying rock. The ore must then be processed, creating an enormous quantity of waste – about 100 billion tonnes a year, more than any other human-made waste stream. Mineral extraction and processing consumes a lot of energy, and the mining industry is one of the single-biggest emitters of greenhouse gases. In 2018, its global emissions amounted to 3.6 billion tonnes of carbon dioxide, about 10 per cent of total human-generated greenhouse gas emissions.

Mining also has well-documented environmental and social costs. One recent study of mineral extraction in the Brazilian Amazon found that the environmental impact of a single mine can ripple out for 70 kilometres in every direction. That isn't just a question of the toxic waste that is often produced, but stuff like roads for moving materials. "It's the infrastructure associated with the project," says study leader Laura Sonter at the University of Queensland in Brisbane, Australia, plus the secondary pressures as people come to live and work there and other industries spring up.

All of this gives pause for thought as the world seeks to wean itself off fossil fuels. Like-for-like, clean energy technologies require vastly more minerals than their dirty counterparts, as components of batteries, wind turbines, solar panels and electricity transmission and distribution lines (see "The new mineral world", page 41). According to IEA figures, an electric car requires six times more minerals, excluding steel and aluminium, than a petrol one, and an offshore wind plant 13 times more than a gas-fired power plant of equal capacity. The growth of renewables means that it already takes 50 per cent more minerals to generate a unit of electricity than it did in 2010. For some minerals, growth in demand will be an order of magnitude higher.

For the IEA, the principal concern surrounding these critical metals is keeping the lights on, the issue that has energised the agency since it was formed after the oil crisis of the 1970s. It sees possible darkness ahead – because of a looming mismatch between mineral demand and supply. "We are expecting some huge demand increase for many of the minerals vital for the energy transition," says IEA analyst Tae-Yoon Kim. "This could make the energy transition either more expensive or delayed."

Already, this year has seen steep price rises for some essential minerals and metals. At the time of writing, lithium had roughly trebled in price and cobalt had risen by about 60 per cent. Copper, which the IEA describes as "a cornerstone for all electricity-related technologies", with uses in power lines, batteries, solar panels and more besides, was up by about 25 per cent because of a lack of sufficient high-quality deposits. Battery-grade nickel, too, is in short supply, and there are also concerns around the rare earth metals.

That isn't a symptom of insufficient known reserves we could extract now, says Bond. "We have in the Earth's crust between dozens and hundreds of years of supply of the minerals required." The problem, says Kim, is that mining companies aren't yet sure that grand ambitions for a climate transition will be realised, and so are nervous of making the large investments needed to mine these reserves. Governments need to start sending stronger market signals to the mining industry that the energy transition is go, he says.

According to the IEA, the average length of time it takes to convert a known mineral deposit into a productive mine is 16.5 years. The first decade or so of that is planning and feasibility studies, and then it takes another four or five years to dig the mine and build the infrastructure. There is some scope to reduce the planning phase, but there will still be a squeeze on supply in the coming decades.

"Demand for critical minerals is set to increase by a factor of six"

Even then, "dig, baby, dig" isn't the answer to energy security. Many known mineral deposits are concentrated in a handful of countries, sometimes quite unstable ones. Most of the world's cobalt is in the Democratic Republic of the Congo (DRC), much of the lithium in Bolivia and Chile, battery-grade nickel is concentrated in Indonesia and 60 per cent of rare earth production takes place in China (see diagram, bottom of page 41). "That is a concern from a geopolitical point of view," says Kim. Trade disputes or natural disasters in important producing countries can have a major effect on global supply and prices. "Scaling up of supplies from diversified sources is quite crucial," says Kim. To that ›

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A cable car carries workers to the Grasberg copper and gold mine in Papua, Indonesia

GEORGE STEINMETZ/GETTY IMAGES

end, governments should step up their geological survey work to find new deposits, he says. From what we know now, Australia, Canada, Chile, the DRC, Indonesia, Peru and the US could be the big winners of a green mineral boom.

The worry expressed in many quarters is that in our rush to extract these minerals, we risk cancelling out the environmental gains of the clean energy transition. In some cases, concerns about environmental sustainability are already a barrier to filling supply holes. With nickel from Indonesia, for example, much of it is under areas in or close to national parks or other protected areas.

There is no reason, however, to think that overall the green minerals boom will spawn an environmental problem equivalent to the one it aims to solve, says Bond. "You've got to think about the scale," he says. Our current energy system requires us to harvest and process 13 billion tonnes of fossil fuels a year, he says. The equivalent figure for critical minerals is 43 million tonnes. "It's 300 times less stuff," says Bond. "It just stands to reason that it's going to have a smaller environmental impact."

In terms of greenhouse gas emissions, that case is unarguable, says George Kamiya, another IEA analyst. Across its lifetime, an electric car produces half the emissions of a petrol one, even accounting for those associated with mining and processing the lithium, cobalt and nickel in its battery (see diagram, bottom of page 43). If the battery is recharged from renewable sources of electricity, that footprint halves again. The same is broadly true of other green energy technologies.

And unlike fossil fuels, which once burned stay burned, mineral resources can be reused, in many cases potentially hundreds of times. With better recycling of, say, cobalt and nickel from dead car batteries, mining intensity ought to fall over time. Whether this can happen is an open question. "Recycling is quite well established for bulk metals such as steel, aluminium and copper, but that's not yet the case for others such as lithium and rare earth elements," says Tim Gould at the IEA. "That will have to change."

The IEA estimates that between 2030 and 2040, the amount of recycled minerals in the supply chain – mostly copper, cobalt, nickel and lithium from spent batteries – will need to increase from around 100,000 tonnes a year to 1.2 million tonnes, about 10 per cent of total demand. Most importantly, that will require economies of scale to make recycling viable, says Kim. To that end, manufacturers need to design products that are more easily recyclable, and politicians need to encourage more efficient waste collection and sorting, he says.

Kim also sees a role for innovation. When rising demand for photovoltaics pushed up demand for silver and silicon, manufacturers responded by reducing the quantity of both required in a solar panel. There are probably similar efficiency gains to be squeezed out elsewhere, as well as scope to substitute one mineral for another, especially among the rare earth metals, a group of 17 elements that share many physical and chemical characteristics.

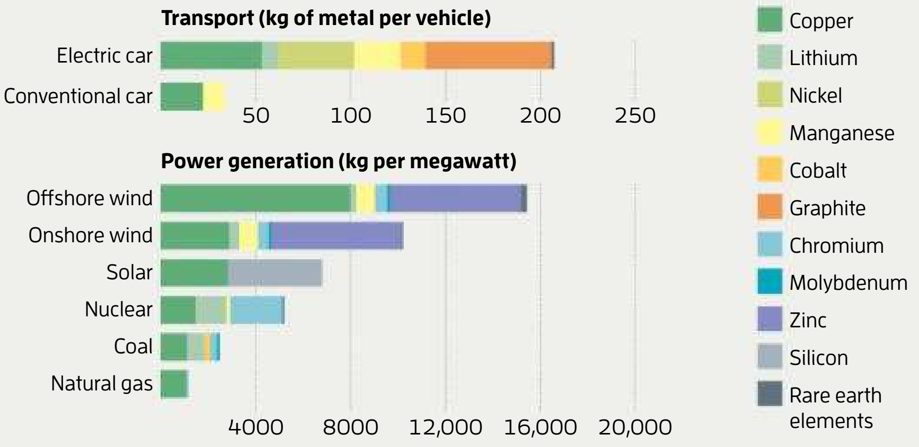
But greenhouse gas emissions aren't the only existential environmental crisis facing humanity. The UN recognises two others – the destruction of biodiversity, and waste and pollution. On both these fronts, mining doesn't get such a clean bill of health.

> **"Mining is already our single biggest source of waste"**

THE NEW MINERAL WORLD

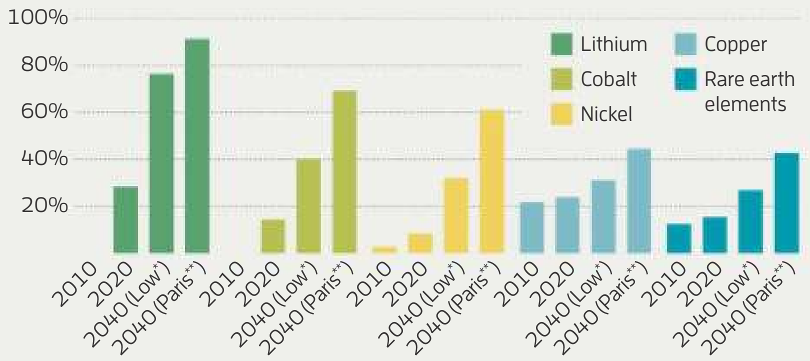
Green energy tech is set to transform demand for key metals

Clean energy technologies require vastly more metals than dirty equivalents



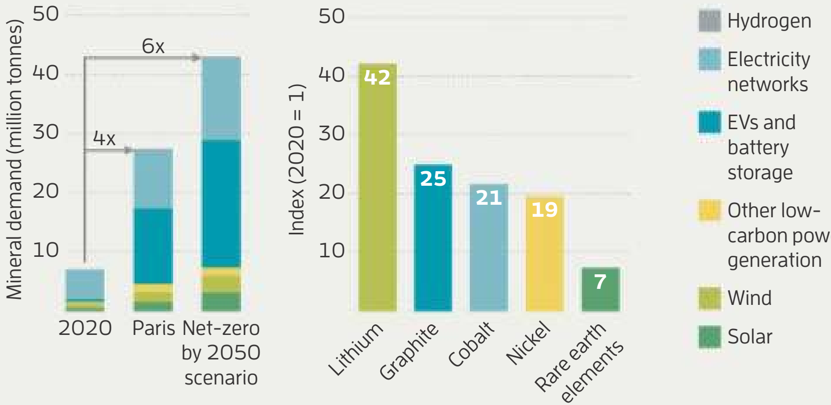
(Steel and aluminium excluded)

Demand for key metals is set to boom over the coming decades as a result



*If current declared clean energy policies are enacted.
**If clean energy policies consistent with the Paris climate change agreement are enacted

Metals for electric vehicles and batteries will see particularly high growth



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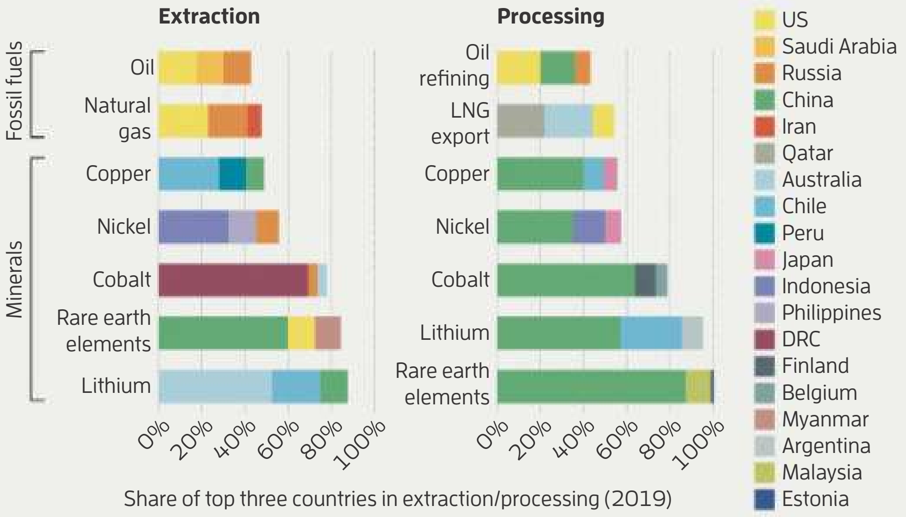
Key elements are more geographically concentrated than fossil fuels



SOURCE: IEA Report/role of critical minerals in clean energy transitions

Earlier this year, a team at the Vienna University of Economics and Business in Austria published an analysis of the impact of existing mining on vulnerable ecosystems. It looked at nine metal ores: bauxite (a source of aluminium and gallium) and those of copper, gold, iron, lead, manganese, nickel, silver and zinc. The extraction of all of these, except lead, has boomed in the past two decades. In 2019, 79 per cent of the ore extracted originated from five of the six most species-rich of Earth's biomes: deserts and dry shrublands; tropical and subtropical moist broadleaf forests; temperate broadleaf and mixed forests; montane grasslands and shrublands; and tropical and subtropical grasslands, savannas and shrublands. Since 2000, extraction from the most species-rich biome of all, tropical and subtropical moist broadleaf forests, has more than doubled, due largely to expansion in New Guinea, India and Indonesia.

The team also found that half of the world's metal mines are 20 kilometres or less from protected areas – recall that a mine's footprint can have a radius of 70 kilometres. And 8 per cent of global production of the metals it looked at in 2019, amounting to 480 million tonnes, was mined within protected areas. The researchers didn't directly link mining activity to environmental damage, but there is ample evidence of that from case studies, says team member Stefan Giljum.

Waste is part of that picture. Mining is already the single biggest source of anthropogenic waste, largely in the form of rock removed to get at ores. The associated problems are well documented. Poorly maintained tailings dams are a particular issue. These are dams, often themselves built up from waste rock from mining, used to contain mining by-products. Frequently, they fail, sometimes spreading toxic slurry over a wide area. The Cobriza tailings dam failure in Peru in 2019, for example, released 67,000 cubic metres of cyanide-laced copper waste into the Mantaro river. Such collapses can also kill large numbers of people; another 2019 disaster at Feijão in Brazil unleashed a mudslide that killed at least 237.

One mine causing particular concern at the moment is the Grasberg copper and gold mine in Papua, Indonesia. One of the world's largest mining projects, it sits right next to the largest national park in South-East Asia, Lorentz National Park, which is home to outstanding biodiversity and a range of important ecosystems. The mine has been directly linked to pollution of fresh water in the park.

Again, a minerals boom is only going to intensify such pressures. In 2020, a team led by Sonter totted up the global footprint of not just present, but also future prospective mines. It gathered information on all of the world's documented mines, of which there are more than 62,000, including about 45,000 in development. The team found that these would collectively affect an area of up to 50 million square kilometres, more than a third of all land, excluding Antarctica. That assumes that mining sites have an impact on biodiversity extending 50 kilometres in all directions, a more conservative figure than Sonter's earlier research in the Amazon implies.

The team also found that 31 per cent of this land is in areas designated as important for halting biodiversity loss, with 8 per cent formally protected. One in seven protected areas has a current or future mine in it, or near enough for its effects to be felt. Over 80 per cent of the mines, both active and planned, do or will produce minerals crucial for the energy transition. "I think it will be really challenging to achieve the energy transition without creating another huge environmental problem," says Giljum.

Sonter's analysis is just a rough indicator of where mines might be in the future, however. "There's a lot of exploration and prospecting in places that will never be developed for a number of reasons – it might be economic, or it could come down to environmental factors," she says. Analyses such as hers can be used to aid decisions on where to site mines, so as to limit their impact in areas important for biodiversity conservation. "There is a lot of opportunity for us to strategically invest in mining outside of these conservation areas," she says.

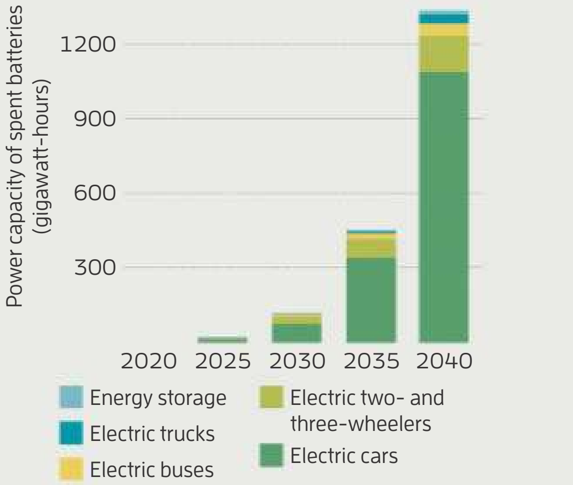
But international bodies seem to be behind the curve: new mines aren't explicitly acknowledged as a threat in the UN's new Strategic Plan for Biodiversity. "Mining isn't mentioned at all," says Sonter. "I'm constantly shocked that agriculture and forestry get mentioned specifically, and mining is just kind of pushed to the side."

A spokesperson for the UN acknowledges that mining and mineral processing aren't expressly mentioned, but points out that they are covered by many of the targets, including target 15, which asks businesses to move towards full sustainability of extraction and production practices, sourcing and supply chains, use and disposal, and reduce associated biodiversity related risks.

There are indications that the industry has got the memo, says Sonter. "I think there's a broad understanding that social licence to operate is really important and environmental factors need to be considered," she says. Some mining companies are also investing in solar-powered zero-carbon mines and low-impact extraction techniques that have been compared to keyhole surgery, where minerals are leached out via boreholes rather than dug up. At present this practice only works for uranium, but could be adapted to other metals.

"Here in Australia, when you fly, you see lots of mines scarring the landscape. If we could avoid that, it would be fantastic," says Henning Prommer at the University of Western Australia in Perth, who is working

The spread of electric vehicles will hugely increase volumes of spent batteries...



Assumes clean energy policies consistent with meeting the Paris climate change goals

A 2019 mining dam collapse at Feijão in Brazil (above) killed at least 237. An aerial view of Indonesia's Grasberg mine (below)

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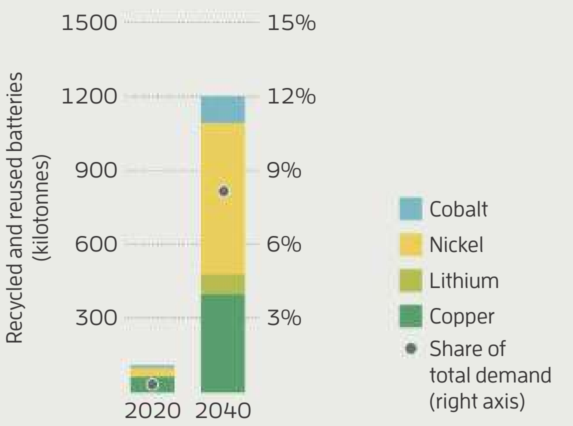
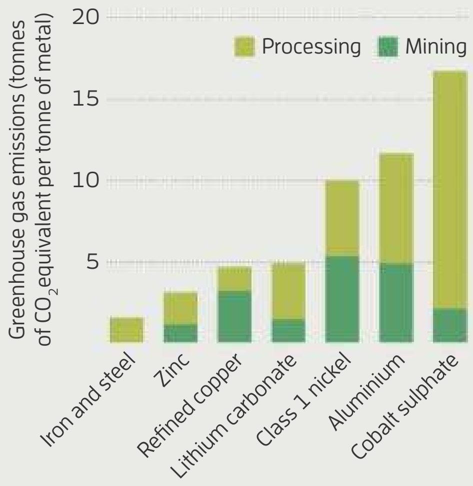
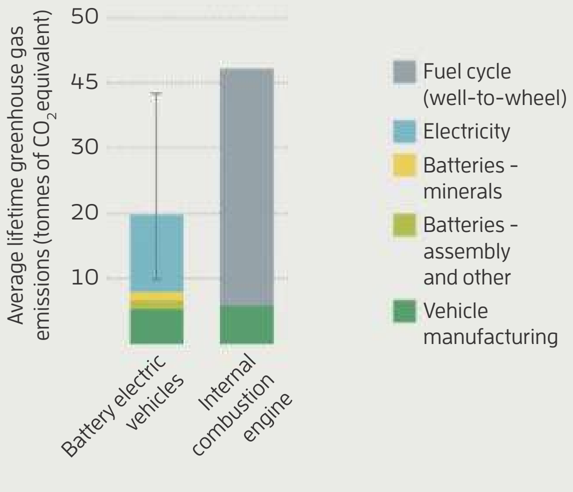
... implying a much greater role for recycling of the minerals involved in future



The mining and processing of crucial metals produces huge greenhouse gas emissions...



... but even so clean energy technologies such as electric cars have a clear climate benefit



SOURCE: IEA Report/role of critical minerals in clean energy transitions

PABLO COZZAGLIO/AFP VIA GETTY IMAGES

Trucks load brine at a lithium extraction plant on the Uyuni salt flats in Bolivia

> **"Destroying nature to be more sustainable would be the ultimate irony"**

on a technique for extracting copper that way.

At present, however, the minerals boom is also stimulating a lot of unsanctioned mining in places like the DRC. "High prices for strategic metals are driving a great deal of illegal and illicit mining in frontier areas, with severe environmental impacts," says conservation biologist Bill Laurance at James Cook University in Australia. "Wildcat miners not only degrade the land and water, but also poach wildlife."

But even conservation biologists acknowledge that the energy transition has to happen, and not just for the sake of the climate. "Mitigating climate change is an incredibly important part of achieving global biodiversity conservation goals," says Sonter. "We're not suggesting that continuing with fossil fuels is the way to go." The balancing act, says Laurance, is to avoid destroying nature as we try to make humanity more sustainable. "That would be the ultimate irony," he says.

We have no choice but to walk that tightrope, says Bond. The IEA's road map for doing so involves six major challenges. Governments must bolster investor confidence; companies need to get innovating; recycling must improve; supplies need to be made more secure, possibly through strategic stockpiling; coordination between producers and consumers has to get better; and environmental and social standards have to improve.

Ultimately, says Birol, it requires us all to dig the fact that when it comes to the energy transition, "minerals are not a sideshow, but a part of the main event". ▮

Graham Lawton is a staff writer at *New Scientist*. His latest book is *Mustn't Grumble* on the surprising science of everyday ailments

Between the numbers

Fractional calculus is helping us model complex systems better than ever before to solve real-world problems, from pollution to pandemics. **Michael Brooks** reports

IT IS the ultimate "your life in their hands" moment. The anaesthetist is counting down from 10. You are about to lose the ability to feel, to breathe independently. From the instant you lose consciousness, you are relying almost entirely on that anaesthetist to keep you alive and stop you waking mid-surgery. Almost, because human judgements on how best to regulate the flow of drugs are themselves reliant on mathematical models underlying the monitoring systems that anaesthetists use.

At the heart of those models is calculus, the branch of mathematics that lets us explain and predict how change happens. This ability is absolutely fundamental to science, which calculus has crucially underpinned since its invention in its modern form a little over 300 years ago.

Now we could be moving to the next level. Conventional calculus has its limits when we try to model complex situations. Patient response in anaesthesia is one – hence why there is always an anaesthetist in the room. But a radical, rapidly evolving form of calculus developed in the past few years is giving us a host of mathematical tools that promise to let us understand the finest details of physical processes with unprecedented precision.

It isn't just drug delivery that could see concrete benefits – it could help us solve all manner of problems, from detecting cancer to preventing the spread of pollution to making more efficient batteries. "I can't count the number of ways in which this can be applied," says Abdon Atangana at the University of the Free State in Bloemfontein, South Africa, who discovered some of the key maths behind the breakthrough.

The original calculus gives us a way to model systems in which there is change and so make predictions. Take speed of motion. What happens when you press a car's accelerator pedal? You get an increase in speed, yes, but how fast the car accelerates depends on a number of factors: the speed at which it was already travelling, how powerful the engine is, how much force was applied to the pedal, whether you are going uphill or downhill and so on.

"Calculus gave us the modern world, and yet it has its limitations"

Calculus lets you figure this stuff out. In doing so, it has given us the ability to control many aspects of the material world. Indeed, it is no exaggeration to say that calculus drove the scientific revolution, which in turn wrought the industrial revolution and, ultimately, the modern world.

And yet for all that, calculus has its limitations. Consider differentiation, one of the two main processes performed in calculus. Differentiation tells us the rate of change of something. In a car journey, it can give you the rate of change of the location of the car, something we normally call speed. This is known as a first-order derivative – being the first time you have performed differentiation on the original property. A second-order derivative would be the rate of change of that rate of change. We know this, the rate of change of speed, as acceleration. You can go further still: you could perhaps imagine calculating the rate of change of acceleration too, which would be a third-order derivative.

The problem is that we only ever perform differentiations in whole numbers, or "integers" – finding first, second, third or even higher-order derivatives. That gives us no way to derive quantities that exist in between those whole numbers. And yet there is plenty of action in the mathematical spaces in between orders defined by whole numbers. It might not make intuitive sense, as with speed and acceleration, and it is hard to get your head around what is meant by two-thirds of a rate of change of something, for instance. But in mathematical terms, such "fractional" calculus should have a lot to offer.

So could there be a way to calculate what is going in these in-between spaces, or what mathematicians call fractional order derivatives? As it happens, the mathematician Gottfried Leibniz, who co-invented calculus, was confronted with this very question by Guillaume de l'Hôpital in 1695. Leibniz didn't know the answer, but his reply to his fellow mathematician was prescient. "It will lead to a paradox, from which one day useful consequences will be drawn," he said.

It isn't clear whether there really is a

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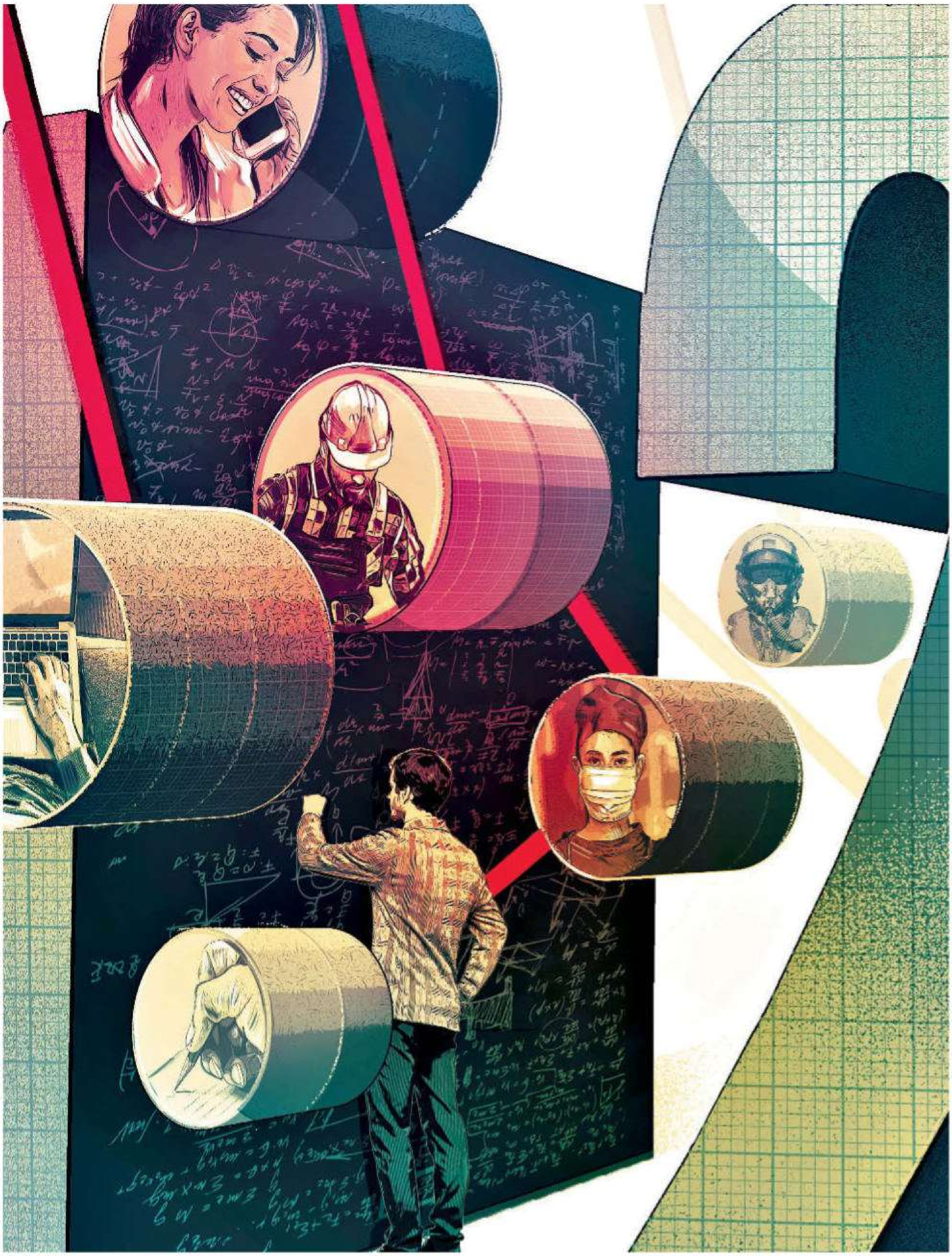


CHRIS MALBON

paradox, but Liebniz was right about this usefulness. Calculating change in the spaces where conventional calculus can’t reach – where things get ever more complex – gives us even greater insight into, and control over, the material world. For example, in systems controlled by feedback from sensors and other instruments, devices relying on standard calculus don’t work as well as they might in principle. In systems that control vertical take-off and landing systems in aircraft such as the Harrier jump jet, say, or suppress the vibrations on the wings of commercial aeroplanes, conventional calculus tends to give only approximate solutions, never fully achieving the goal. Fractional calculus, on the other hand, offers fine-tuning.

The same applies to much of what goes on inside your body. Viscoelastic materials, which are ubiquitous in biological systems, have properties somewhere between those of liquids and solids. They resist modelling by ordinary calculus because each phase of matter requires a different form of calculus. You might model the motion of a viscous liquid by a first-order differentiation because viscosity generally depends on speed of movement. Equally, you could model an elastic solid by a second-order differentiation, for instance – relating to acceleration, as when a stretched elastic band is released. Neither is quite right for modelling a material like arterial walls or heart muscle, however, where the behaviour and properties of that material depend on the forces they are experiencing. Put simply, you want something in between the two orders that can model in-between states.

This is where fractional calculus comes in. The first steps towards making it work came long after Leibniz’s enigmatic statement. In 1832, mathematicians Bernhard Riemann and Joseph Liouville worked out a way to do the second of the two operations in calculus, known as integration, in fractions. In standard calculus, integration is the reverse process of differentiation: if you integrate speed over time, for instance, you get the distance covered. Riemann and Liouville showed that just as you can perform repeated integrations on the result of an integration, you can also create a recipe for doing this partially, giving a fractional integral.

The next significant step forward came in 1967, when mathematician Michele Caputo came up with a new way to define a fractional integral and its inverse, the fractional derivative. His work opened the floodgates to further ways of creating fractional integrals: once mathematicians saw Caputo’s innovation, many worked out how to create similar tools. “There are new definitions being created all the time in recent years,” says Arran Fernandez, who studies the mathematical properties of fractional calculus at Eastern Mediterranean University in Cyprus.

> **“Fractional calculus is different in that it models something akin to memory”**

There are now myriad mathematical processes known as operators that create fractional integrals. In fact, the mathematical literature is full of fractional operators, each designed for a different task, and all of them useful in some way. “The only reason we use mathematics is to try to capture and understand nature, but it’s impossible for a single mathematical operator to do that,” says Atangana.

He worked out his own fractional operator in 2015 and sent the result to Dumitru Baleanu at Çankaya University in Ankara, Turkey, to be checked. Baleanu was impressed. “When he read it, he said to me, ‘you have opened the doors of heaven’,” says Atangana. The reason for the excitement was that Baleanu could see that the Atangana-Baleanu operator, as it is now known, would prove remarkably useful across a wide range of applications. He wasn’t wrong.

That is partly because it offered an alternative to the way fractional integration had been done up to that point. This involved using a “power law”, a mathematical relationship between two factors, where one changes as a power of the other – as its square or a cube, for example. We see power law relationships in all kinds of natural phenomena. Earthquakes are one example: the likelihood of an earthquake of a particular magnitude happening within a particular window of time is related to that magnitude

All kinds of complex systems can now be better analysed

THANA PRASONGSIN/GETTY IMAGES

by a power law known as the Gutenberg-Richter law.

The problem with power laws is that they describe processes that have no well-defined beginning and end, and only provide an approximate description of how something is evolving. “They really only serve as first-order approximations,” says Ernst-Jan Wit at the University of Lugano in Switzerland.

Atangana’s fractional operator swapped out the power law term for something known as a Mittag-Leffler function, which would give his tool the capacity to account for unexpected changes that would pass unnoticed by conventional calculus – promising more precision, but also more versatility.

Imagine groundwater polluted with toxic waste that is seeping into a farmer’s soil, for instance. It travels slowly and disperses in a diffusive manner, spreading out over a large area. But if it encounters a fracture in the subsoil, everything changes. “When water meets a fracture, it will go inside the fracture and start running very fast,” says Atangana.

As well as being faster, the flow will be much more directed. These two different kinds of flow mean the system goes through two phases of very different behaviour, a phenomenon known to mathematicians as “crossover”. That has always dictated the use of entirely different mathematical models, making the calculations too complex. But Atangana found a way to overcome that problem, allowing someone to analyse the entire system as it evolves with just one operator.

“Nature is full of things that exhibit crossover,” says Atangana. Mathematicians looking to model the spread of disease, for instance, have turned to his operator in droves. In 2018, Baleanu and colleagues from Turkey, Nigeria and Pakistan showed that the new operator was able to give solutions to a previously insoluble problem: how best to vaccinate when an epidemic involves two strains of a pathogen wreaking havoc on a population.

The best effort, based on standard calculus, had involved solving six extremely complex equations, all patched together. Worse still, they only worked if you could find a combination of the equations’ variables that made the equations reflect real-world values – a laborious process that had to be done by trial and error. With the Atangana-Baleanu operator in play, the researchers quickly found a solution that gave a closer match to the real-world data on the spread of the strains. It has already proved useful in modelling the spread of covid-19 through some populations.

ALBERT YURALAITS/ALAMY

Fractional calculus has been used to guide vaccination strategies

Total recall

Baleanu and his colleagues put this success down to the fact that fractional operators, including the Atangana-Baleanu operator, can model something akin to memory. Think of the time it takes for a laptop battery to lose all of its charge. If it is an old battery that has been through many charging cycles, its useful life will probably be a lot shorter than if it is new. Standard calculus has no way of taking such memory effects into account, making predictions unrealistic. Models and control systems based on fractional derivatives, on the other hand, can factor this kind of thing into their operation.

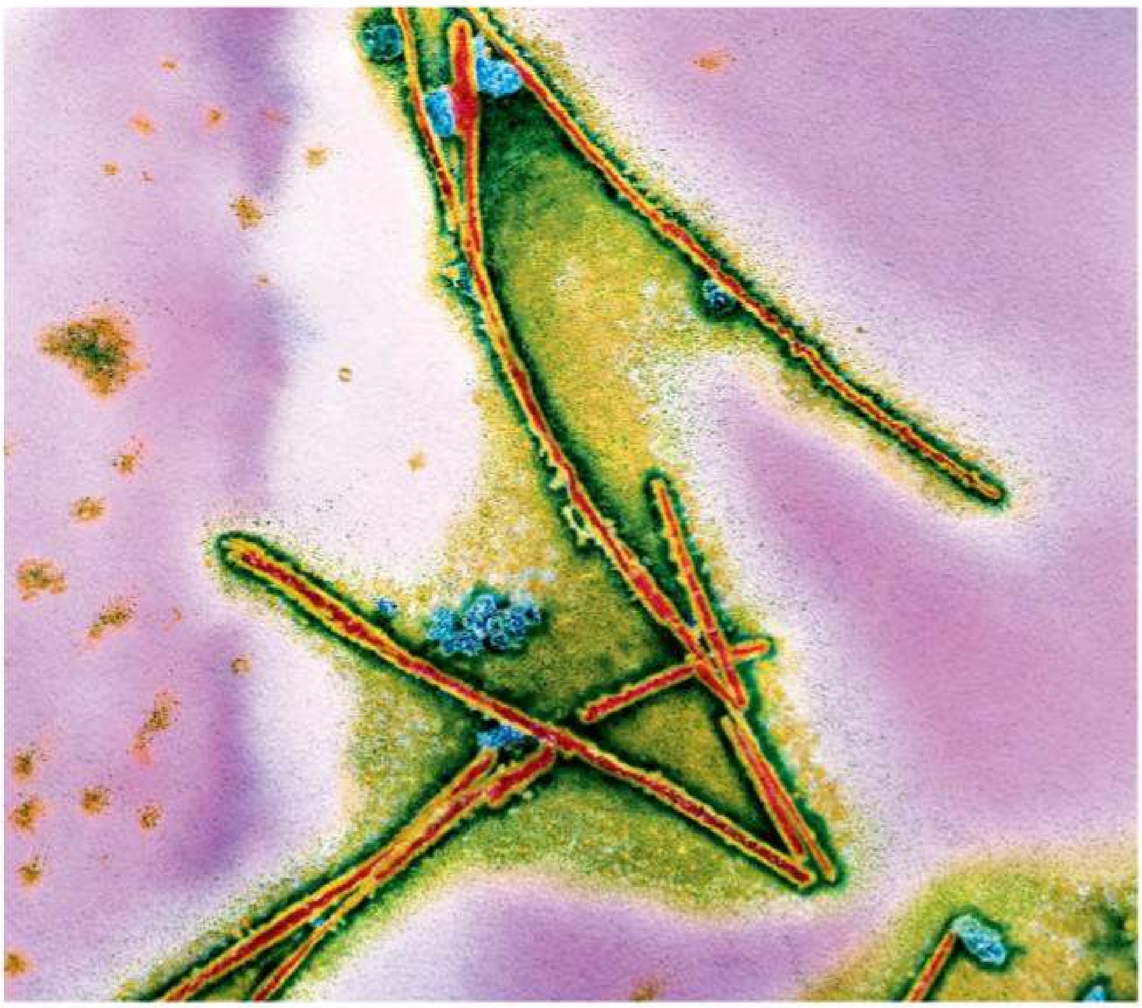
The power of this aspect of the fractional operator is perhaps best demonstrated in anaesthesia, where memory is also central to the idea of computer-controlled monitoring and drug delivery. “I can use the memory term to track the drugs and avoid overdosing,” says Dana Copot at Ghent University in Belgium.

The way our body processes drugs depends on their concentration in the bloodstream. It is hard to find ways to keep the concentrations of drugs in the blood at their optimal level. Standard calculus can’t model the process accurately: it is too blunt an instrument, and under or overshoots the real-world data. As a result, patients might get too little anaesthetic – causing them to wake or feel pain mid-operation – or too much. But fractional calculus can incorporate a memory of what has already been administered. “With the memory term, we can capture all the characteristics,” says Copot. This allows researchers to find out exactly what amount of which drug should be administered and when.

So although it might be a while before a computer is administering your anaesthetic, Copot is confident that it could be possible one day. After all, fractional calculus is already starting to enter the consulting room. Copot is part of a collaboration that has used it to develop a system for differentiating asthma from chronic obstructive pulmonary disease. It works by comparing physiological symptoms against those predicted by a model with a range of fractional orders. And many more uses of fractional operators will probably emerge over the coming years. Other medical researchers are suggesting that fractional calculus can enable better models of how cancers spread, and how treatment regimes might affect their growth. Outside medicine, a team at Shandong University in Jinan, China, showed earlier this year that fractional operators can give a better live estimate of an electric car’s range by more accurately modelling all the myriad changing factors that are draining its battery.

Not that fractional calculus will be all-conquering. “The only reason we use mathematics is to try to capture and understand nature, but nature is complex, and nature is above mathematics,” says Atangana. Yet there is no doubt that fractional calculus will reveal more of the finer details of nature’s glorious messiness than any mathematical tool available to us previously. Leibniz’s 300-year-old prediction has proved as accurate as anyone could have hoped. ▮

Michael Brooks is a *New Scientist* consultant and author of *The Art of More: How mathematics created civilisation*



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The Jekyll and Hyde proteins

The weird prion proteins that cause horrifying brain diseases have another side to them, as neuroscientist **Michel Brahic** explains

I WAS at my laboratory bench one morning in 1980 when a colleague walked in and declared that he had identified the cause of scrapie, a mysterious and fatal infection that leaves tiny holes in the brains of sheep and goats. Stanley Prusiner had been studying the disease for some years and was stirring up controversy with his outlandish claim that the scrapie agent lacked genes or indeed any genetic material. It was, he said, an infectious protein – something never heard of before.

His issue that morning was what to call this unique protein. He had two candidates: "piaf" and "prion". I have forgotten what piaf stood for, but I remember pointing out that the name was already taken by a popular French singer. Fine, he said, in any case he preferred prion, a contraction of protein and infection. I agreed. What I didn't say was that in my native French tongue *prions* means "let us pray" – and that if he persisted with his idea of infectious proteins, he would need prayers.

Prusiner held strong in the face of adversity and, in 1997, won a Nobel prize for his discovery. By then, prions had been linked to Creutzfeldt-Jakob disease (CJD) in humans and to bovine spongiform encephalopathy or "mad cow disease". There were also suggestions that they were involved in common neurodegenerative diseases including Alzheimer's. What nobody predicted was the existence of "good" prions. We now know that prions emerged early in the evolution of life and play essential biological roles, from giving yeasts the ability to rapidly adapt to allowing you to form long-term memories.

The story of prions didn't start with Prusiner. Back in the 1950s, two medics, Carleton Gajdusek and Vincent Zigas, were in the remote highlands of New Guinea puzzling over the cause of kuru, a strange neurological disease that was spreading among local populations. They managed to perform autopsies on people who had died of kuru and, between 1957 and 1959, they published articles describing the disease and their discovery that the brains of those with it showed a loss of neurons and myriad microscopic holes. These papers caught the attention of a veterinarian called William Hadlow who, in a letter to *The Lancet*, pointed out the similarities between kuru and scrapie. Scrapie was known to be infectious, but with an extremely long incubation period. To test the link, Hadlow suggested inoculating animals with extracts from the brains of people with kuru. Sure enough, when Gajdusek did the experiment on chimpanzees, the apes came down with a kuru-like disease, but only after 20 months.

That still left the question of how kuru was transmitted outside the lab. The prime suspect was a peculiar mortuary rite of the New Guinean highlanders – the only people known to contract kuru – that entailed eating the flesh and brains of the dead. This transmission route was confirmed by the fact that no case has been observed in people born after the cessation of ritual cannibalism.

Strange contagion

We now know that other transmissible spongiform encephalopathies spread in a similar way. Sheep get infected with scrapie by eating grass contaminated by saliva and other secretions, and by eating the placentas of lambs. Bovine spongiform encephalopathy spreads when cattle eat feed containing meat and bonemeal from other infected animals. CJD doesn't spread by physical contact with a carrier, either. It arises spontaneously in around one in every million people per year, and has in the past been transmitted accidentally through contaminated surgical material or injections of growth hormone extracted from human cadavers.

That a protein could be infectious was heretical when Prusiner coined the name prion. Other infectious diseases are caused by microbes and viruses, all of which have genes that allow them to replicate and spread. Doing this without replication of DNA or RNA was considered impossible. Fortunately, we now think we know what makes prions infectious.

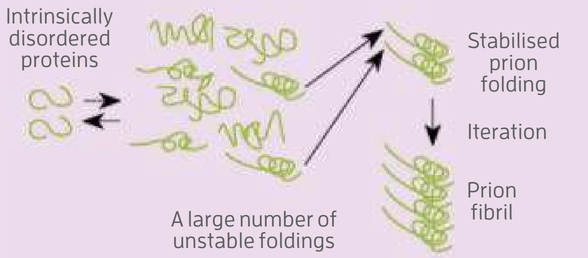
The chain of amino acids that makes up any protein must fold in a precise way to give the protein its shape and function. Prions belong to a group called intrinsically disordered proteins, which cannot do this unless they are bound to a specific partner. Until then, they fold and unfold into many thousands of unstable intermediate forms, lasting just milliseconds each. Uniquely, prion proteins have an alternative way to fold into a stable form: one unstable intermediate binds to another in the same configuration. This is called self-templating and is what creates a prion. The probability of this happening is extremely low, but when it does, the combination of two identical subunits is very stable. The resulting prion then binds and stabilises more prions with the same shape, eventually forming a thread-like fibril, which is visible using an electron microscope (see "How can a protein be infectious?", below).

Cells are equipped with a quality-control system that steps in when protein folding goes astray. Under normal circumstances, misfolded proteins are either unfolded and correctly refolded or simply degraded – and this is what usually happens when prions form. However, the control system sometimes amplifies the problem by fragmenting the fibrils to create smaller seeds from which more can grow. This, it is thought, is how prions spread from cell to cell like an infectious agent.

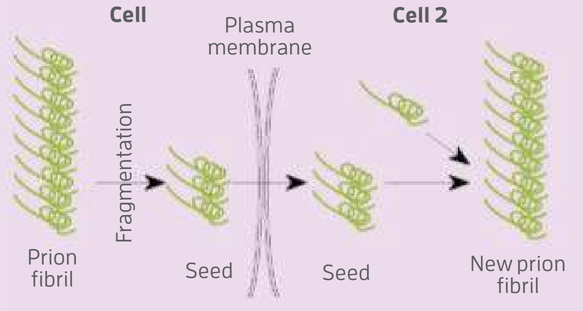
How prions cause diseases isn't yet known. They may be toxic for infected cells. Another possibility is that turning more and more of a particular protein into its prion form might deprive the cell of a crucial component. What has become increasingly apparent, however, is that prions aren't only responsible for transmissible spongiform encephalopathies. Research has focused on the brain – and it may be more susceptible to prion diseases because brain cells don't regenerate well, or at all. But prion diseases have also been found outside the brain. Type 2 diabetes is one example.

How can a protein be infectious?

A so-called intrinsically disordered protein must bind to a partner to form a stable structure. Very rarely, this partner is an identical copy of the same protein and a prion is formed, which grows into a fibril as more identical copies bind to it.


Intrinsically disordered proteins
Stabilised prion folding
Iteration
Prion fibril
A large number of unstable foldings

When a cell's quality-control system tries to correct this mistake, prion fibrils can fragment into seeds. These are small enough to pass into other cells, where they can grow into new fibrils. This is thought to be why prions are infectious.



Prions appear to contribute to a range of neurodegenerative diseases, too. These conditions, which include Alzheimer's, Parkinson's and amyotrophic lateral sclerosis, are characterised by specific brain lesions made of aggregated proteins. It is now generally accepted that these proteins are prions, which spread within the brain like an infection. Some neurodegenerative diseases are associated with more than one prion and some prions contribute to more than one disease through their ability to fold into alternative forms (see "Prions in neurodegenerative diseases", page 50). They spread within a brain through the nerve fibres. Exactly how is unknown, but the realisation that prions contribute to these diseases offers hope that we can find drugs to slow down, or even halt, their progression.

Another intriguing discovery is that prions are evolutionarily ancient. Proteins with the capacity to fold into two functionally distinct configurations, one of which is self-perpetuating, have been found in all branches of life, and even occur in viruses. The fact that these have survived and proliferated raises the question of whether, as well as causing diseases, prions might confer evolutionary advantages. In recent years, experiments have suggested they do – in yeasts, at least.

The other face of prions

A key challenge for life is to adapt to changing environments. Adaptation can occur genetically as a result of random mutations followed by natural selection of those fitter genes. But this is a slow process, even for fast-dividing organisms such as yeast. Moreover, if the environment reverts to its original state, the mutation must be reversed. Prion proteins offer a fast alternative. Studies reveal that changes in a yeast's environment, such as the presence of different nutrients, induce a prion protein to switch into an alternative form that helps the yeast exploit the new food source. What's more, this adaptation is passed on to all the organism's progeny in a unique, non-genetic type of inheritance (see "Protein-based inheritance", page 50).

Experiments showing that prions can give › organisms an evolutionary advantage have, so far, only been done with yeasts. However, good prions – ones that perform useful roles within an organism – have been found in a variety of animals. This line of research began back in the 1970s, when Eric Kandel and his group at Columbia University in New York started exploring the molecular mechanism of memory. Their studies of a simple organism, a sea slug, cemented the idea that creating a long-term memory involves the enlargement of synapses, the points of contact through which a nerve impulse is transmitted between neurons. This requires protein synthesis. The research hinted that prions make this possible.

The puzzle was this: a neuron may have thousands of synapses, so how does it know which one has been stimulated by a nerve impulse and therefore needs to be enlarged? Kandel and his colleague Kausik Si thought that a protein called CPEB might be involved. It is present at synapses and was known to activate the production of other proteins, which could be used to remodel the synapse. Kandel and Si also noticed that CPEB is an intrinsically disordered protein. Might it be a prion, they wondered? To test this idea, they teamed up with Susan Lindquist at the Massachusetts Institute of Technology and substituted the intrinsically disordered CPEB for one in a yeast prion. It made no difference to the yeast. In other words, the CPEB acted as a prion.

This led Si and Kandel to propose that a long-term memory is formed when repeated stimulation of a synapse causes CPEB to fold into a prion. As a result of self-templating, the CPEB prion grows into a fibril, which is too large to move into the neuron. In this form, CPEB activates the production of other proteins that permanently alter the structure of the synapse. It took a long time to get evidence to back up this model, but in 2020 Si, now at the Stowers Institute for Medical Research in Kansas City, and his collaborators confirmed all its predictions in experiments on fruit flies. Meanwhile, a team led by Kandel showed that mice bred so that their CPEB was inactive had impaired long-term memory.

So it seems that prions play a central role in learning in organisms from sea slugs to fruit flies to mammals. And CPEB isn't the only known good prion protein. Others identified so far include proteins essential for the mammalian immune system to respond to viral infections by ensuring a fast delivery of antiviral proteins called interferons.

The hunt is now on for more good prions. We are also starting to understand what distinguishes them from bad ones. The two share fundamental properties such as self-templating, but, unlike bad prions, the good ones studied so far don't spread. Another difference is that the folding of good prions is induced by an external stimulus – chemical stimulation of the synapse in brains, for example, or environmental chemicals in the case of yeasts. This induction is precise and efficient, its mechanism having been refined during millions of years of evolution. The folding of proteins into bad prions, by contrast, is random and rare. That is one reason why neurodegenerative diseases tend to be diseases of old age: the longer you live, the greater the chance of a bad prion forming a fibril and seeding.

We are only beginning to appreciate the importance of prions in biology. On rare occasions, things go wrong and they cause diseases. But the list of good prions is steadily getting longer. Could Zigas and Gajdusek have predicted these developments when they were in New Guinea wondering about the role of cannibalism in the kuru epidemic? Certainly not. The prion story teaches us, once again, the power of pure curiosity to change our understanding of the world. ∎

Michel Brahic is an honorary professor at the Pasteur Institute in Paris and consulting professor at Stanford University School of Medicine

Prions in neurodegenerative diseases

Prion proteins are thought to be associated with at least seven neurodegenerative diseases. Some diseases are linked to more than one prion and some prions occur in more than one disease

<table>
<tr><th>Multiple system atrophy</th><th>Parkinson's disease</th><th>Parkinson's disease dementia</th><th>Dementia with Lewy bodies</th><th>Alzheimer's disease</th><th>Frontotemporal dementia</th><th>Amyotrophic lateral sclerosis</th></tr>
<tr><td></td><td></td><td></td><td colspan="2">Beta-amyloid</td><td></td><td></td></tr>
<tr><td></td><td></td><td colspan="4">Tau</td><td></td></tr>
<tr><td colspan="4">Alpha-synuclein</td><td></td><td colspan="2">TDP-43</td></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td colspan="2">FUS</td></tr>
</table>

Protein-based inheritance

In the mid-19th century, an Augustinian friar called Gregor Mendel unlocked the mystery of inheritance by crossing different strains of peas and observing how their traits – like the colours and shapes of flowers – were distributed among the progeny. It would be almost a century until his findings were explained by the discovery that genes are made of DNA. When individuals reproduce sexually, DNA is replicated and then mixed with that of a partner so that each offspring has traits coming from one parent or the other.

However, since the 1950s, geneticists had been puzzled by traits in mushrooms and yeasts that don't follow Mendel's laws of inheritance, being inherited by all offspring rather than just a fraction of them. Could they have missed something in the way DNA replicates and is distributed among offspring?

In 1994, Reed Wickner at the US National Institutes of Health suggested an answer: these anomalies are explained if the traits are caused by proteins behaving like prions. Prion proteins are characterised by the ability to take different forms. Imagine a yeast cell with a trait due to a protein that can turn into a prion form, so altering that trait. If the cell is then crossed with another yeast with the original protein, all the progeny will receive some prions. These prion proteins will change the regular proteins into the prion form. As a result, all the progeny will exhibit the new trait. Wickner went as far as using the term "protein-based inheritance" to describe this process.

It turned out that he was right. Soon after Wickner proposed his idea, he and his colleagues reported experiments showing that prion proteins are indeed responsible for the non-Mendelian traits observed in yeasts and mushrooms. The conclusion was shocking but inescapable: DNA isn't the only molecule responsible for heredity. In fact, protein-based inheritance isn't even a rarity. It has now been uncovered in all domains of life.

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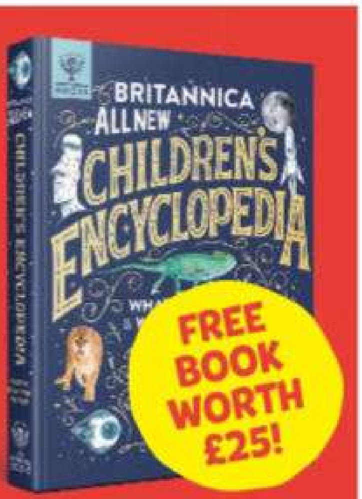

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Citizen science

Gravitational glitch, anyone?

Help find high-energy astronomical events, such as black holes colliding, by volunteering with Gravity Spy, says **Layal Liverpool**

Layal Liverpool is a science journalist based in Berlin. She believes everyone can be a scientist, including you. @layallivs

What you need

Access to Gravity Spy, via zooniverse.org

Citizen science appears every four weeks

Next week

Science of cooking

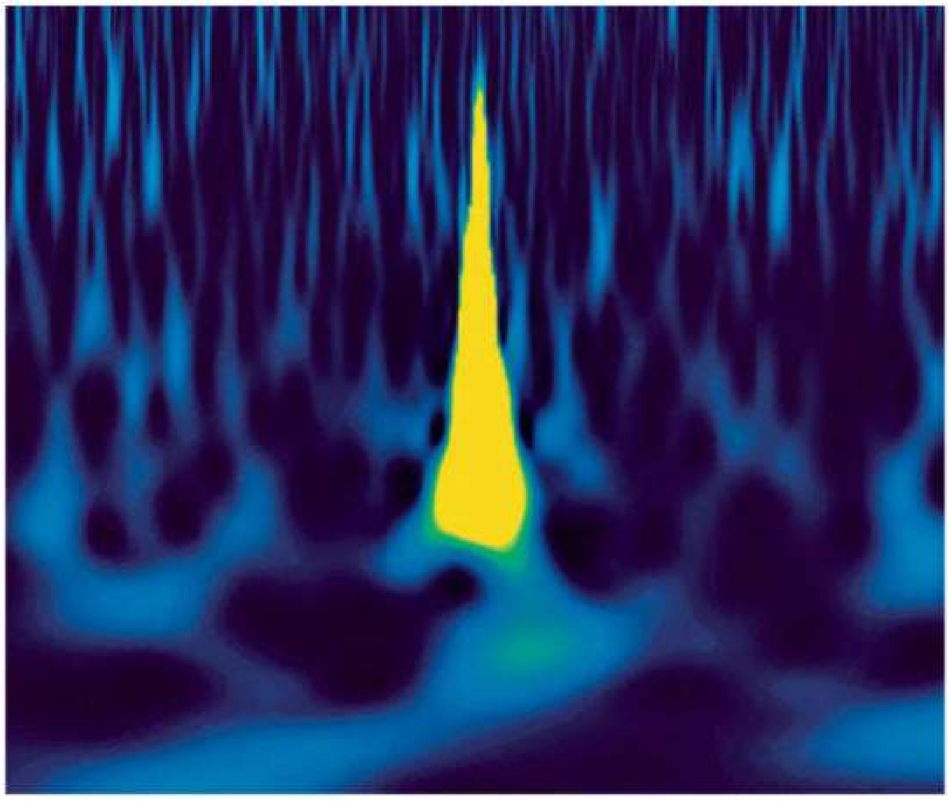
A COLLISION between two black holes was detected for the first time on 14 September 2015. It happened more than a billion years ago, but it generated ripples in the fabric of space-time, called gravitational waves, that were eventually detectable on Earth.

Researchers have since made countless discoveries about events in the universe using the Laser Interferometer Gravitational-Wave Observatory (LIGO), two widely separated gravitational-wave detectors based in the US. Now, they need your help to distinguish more signals from the noise.

Gravitational waves stretch and squeeze everything they pass through. These effects can be used to work out what caused the ripples in the first place. But the search for them can be hindered by glitches in the frequencies picked up by the gravitational-wave detectors, caused by background vibrations, other environmental interference or from the instruments themselves.

More than 26,000 online volunteers with the Gravity Spy citizen science project are helping to tackle this problem, by labelling glitches in LIGO spectrograms, like the one pictured, based on the shapes they form. This helps researchers clean up the LIGO data, making it easier to identify true signals of high-energy astronomical events, such as colliding stars or black holes.

Visit zooniverse.org and search for "Gravity Spy" to get started. I quickly learned how to spot two common glitch patterns, known as "blips" and "whistles", using the online tutorial. Volunteers are helping LIGO scientists and engineers figure out the causes of the glitches in order to improve the detectors, says Gravity Spy team member Kevin Crowston at the Syracuse University School of Information Studies in New York.



SIDDHARTH SONI

"Having a collection of the same kind of glitch is useful to guide the search for what else is going on in the detector at the same time that might have caused that particular kind of glitch," says Crowston. His team also uses the data from volunteers to train AI models to detect and categorise glitches.

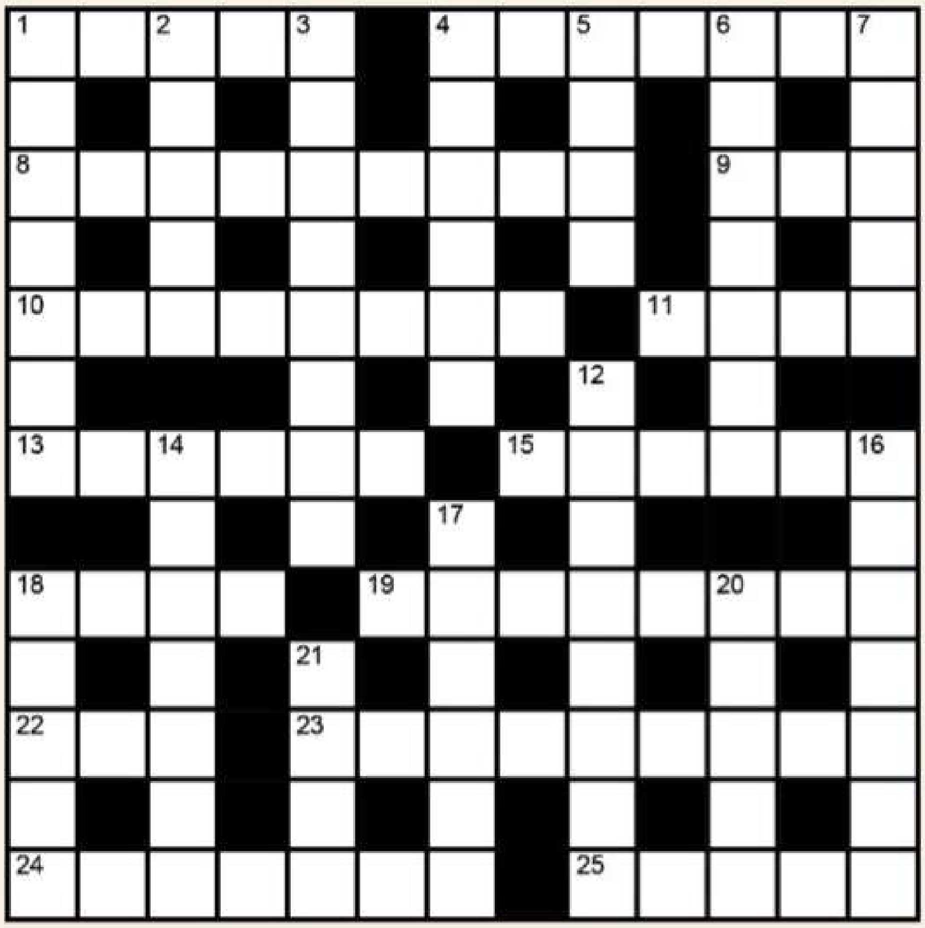
If you spot a strange pattern that doesn't fit into one of the predefined categories, you might have discovered a new type of glitch. "More advanced volunteers identify novel classes of glitches; things that they've noticed because they have looked at so much data that the LIGO scientists don't know about," says Crowston.

Meanwhile, scientists continue to make exciting new discoveries of ripple-generating events in the universe. Signals detected by a LIGO detector and a similar observatory called Virgo in Italy in early 2020 were found to have originated from a black hole swallowing a neutron star more than 900 million light years away from Earth.

Learn more, and get involved, at Gravity Spy. ▮

These articles are posted each week at newscientist.com/maker

Cryptic crossword #70 *Set by Rasa*



Scribble zone

Answers and the next quick crossword next week

ACROSS

1 Musical childminders releasing covers (5)
4 Beauregard briefly cuts up dress parts (7)
8 Giving up, "House of Stairs" artist doesn't finish building section (9)
9 One who strokes mohair evenly (3)
10 Salt absorbed by exposed crustacean (8)
11 Joule and university representative react to a scare (4)
13 Pirate's artillery piece in the sound (6)
15 Handbag at Harrods is too much for Christie, say (6)
18 Keep damaged vase (4)
19 Awful brute breaks sentient machine's ducts (3,5)
22 I'm flipping around transducer (3)
23 Subject for 1 Across, 11 Across and 13 Across: morays, not bats (9)
24 Case of Chianti by rear tank (7)
25 Sultry person getting documentation to replace article (5)

DOWN

1 Medium-sized pen company supporting stout relative, still (7)
2 Less nasty one interrupting CERN restructuring (5)
3 Lift English vessel in upside-down position (8)
4 Check type of shower for the auditor (6)
5 Official Shiba Inu meme (4)
6 Game involved torque applied to clubs (7)
7 Throat ailment upset cats and dogs eating bit of refuse (5)
12 For example, fan of the macabre grips two pieces of toxic cracker? (3,5)
14 Tyros reflecting on bad habits (7)
16 In the lab, tested a second fluid as dye (7)
17 Heavy weight under pressure is moving part of an engine (6)
18 Za'atar ingredient French author raised (5)
20 Dude returned essentially outmoded curling implement (5)
21 Food festival announced (4)

Our crosswords are now solvable online
newscientist.com/crosswords

Quick quiz #127

1 What was the first spacecraft to reach interstellar space?

2 Which term applies to larvae that look like caterpillars: scarabaeiform, eruciform or vermiform?

3 What was the earliest known Meso-American civilisation?

4 The term "robot" was first applied to an automaton in a play by which writer?

5 *Borrelia* bacteria cause which vector-borne disease?

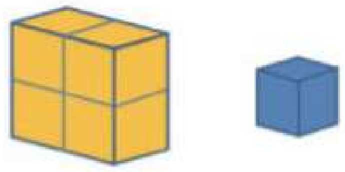
Answers on page 55

Puzzle

set by Katie Steckles

#139 BLOXO cubes

Chloe and Clive are hard at work packing BLOXO kids' blocks in the warehouse. There are two kinds of block: yellows, which are a set of four cubes stuck together to form a 2×2 square, and blues, which come as single cubes.



With a pile of blocks in front of them and a box to fit them in, Clive became despondent. "This box is big enough to fit 27 cubes in a 3×3×3 arrangement and we need to fit in six yellows and three blues, which does add up to 27 cubes. But I'm not sure they're going to fit – some of these awkward yellows are going to stick out the top."

"I'm sure we can work out a way to arrange them so they all go in the box," exclaims Chloe.

"Well, I'm fairly confident they won't fit," replies Clive.

Who is right? Can you prove it? (Playing with some toy bricks might help.)

Answer next week

Changing tune

Will composers run out of new combinations of musical notes to create original melodies? Or are there infinite combinations?

Sandeep Bhagwati (composer)
Concordia University,
Montreal, Canada

A melody is more than just a sequence of notes. Rhythm, variations in loudness and the length of musical phrases all enhance the sequence of notes to make a melody "original". Each of these adds a huge layer of possible combinations. Moreover, the notes that Western composers use are meagre abstractions that represent culturally selected frequencies from the entire, continuous human hearing range.

Most music around the world uses frequencies in between Western notes. With these "microtones", the range of possible notes extends considerably, and so does their combinatorial potential. If you are willing to accept or even invent new musical styles and aesthetics, the potential for composing and relishing new melodies is infinite.

"There must be several googols (10^{100}) of different possible melodies that can be composed without repeating yourself"

MEDLAR/GETTY IMAGES

What is the fate of house spiders that are released outdoors?

This week's new questions

Spider survival **I often catch house spiders and release them some distance away. Can they navigate back? If not, what are their chances of survival?** ***Richard**, Bradford, West Yorkshire, UK*

In hot water **I am right-handed and I find it difficult to accurately judge the temperature of bathwater with my left hand. Why?** ***Robert Morley**, London, UK*

Richard Ellam
Bristol, UK

We won't run out of new melodies any time soon. Although the number of possible melodies is finite, it is so very large that for all practical purposes, the supply of new tunes is infinite.

I play the bagpipes (smallpipes, not Highland) and my pipe chanter only plays nine notes, whereas most orchestral instruments can cover about three chromatic octaves, totalling approximately 36 notes. So if anyone is going to run out of new tunes, it will be the pipers.

We pipers play a lot of marches, and one of the simplest march rhythms is just four quarter-note beats in every bar. If you only have nine notes to play with and four places in a bar to fill, you can have a total of 9^4 or 6561 distinctly different bars. If you assemble these into 16 bars of music, there are 6561^{16} possible arrangements – a very big number. Lots of these tunes would be awful or boring, or wouldn't contain harmonious intervals. But even if only one tune in a billion billion (10^{18}) follows all the other rules for composing pipe marches, you still have something like 1.2×10^{43} possible tunes. And that's only pipe marches – we also play waltzes, jigs, reels, hornpipes, slow airs and the rest.

If you do a similar exercise for instruments with a wider range of notes, and for longer and more complex melodies, you realise that there must be several googols (10^{100}) of possible melodies that can be composed without repeating yourself.

Bryn Glover
Ripon, North Yorkshire, UK

It depends what is meant by "notes". A piano has a finite range of predetermined notes, depending on the fixed tuning of the open strings, but a violin has a theoretically infinite range of possibilities, depending on the variable placing of fingers.

But considering the range of notes represented on a piano, and assuming that the questioner is referring to the standard Western notion of seven-note octaves (A to G), then there is a finite number of notes and therefore a finite number of combinations, however large that number may be. Even if one adds in the scales and ranges of, for example, music from China, India, Bali and elsewhere, the answer will still be the same.

Richard Bridge
London, UK

Composer Sergei Prokofiev, famed for his melodies, gave an answer to this question, which was posed by a reader of *Pioneer* magazine in 1939.

He started with the analogy of chess, calculating that by the white player's fourth move, there are 60 million possible variants. There are also 25^7 variations to choose from in a short tune of eight notes, he said, which offers around 6 billion possibilities. Out of these, a composer might be able to find something melodious. Add in different note lengths, rhythm and harmony, and the 6 billion are multiplied still more.

He added that some melodies once thought to be appealing are not considered so today, and vice versa. He concluded that "we need not be afraid that there will come a time when all melody will have been exhausted and we shall be obliged to repeat old tunes".

Prokofiev is a good source on this: his body of work is full of melodies in a great Russian tradition. I think *Peter's Theme* in *Peter and the Wolf* is one of the most affecting melodies I have ever heard. He was also a chess master, so he knew about options.

Cool sprout

Why do some veg, such as onions, carrots and radishes, continue to grow in the darkness of my refrigerator?

Natasha Aidinyantz
Watford, Hertfordshire, UK

The common feature of the vegetables described in the

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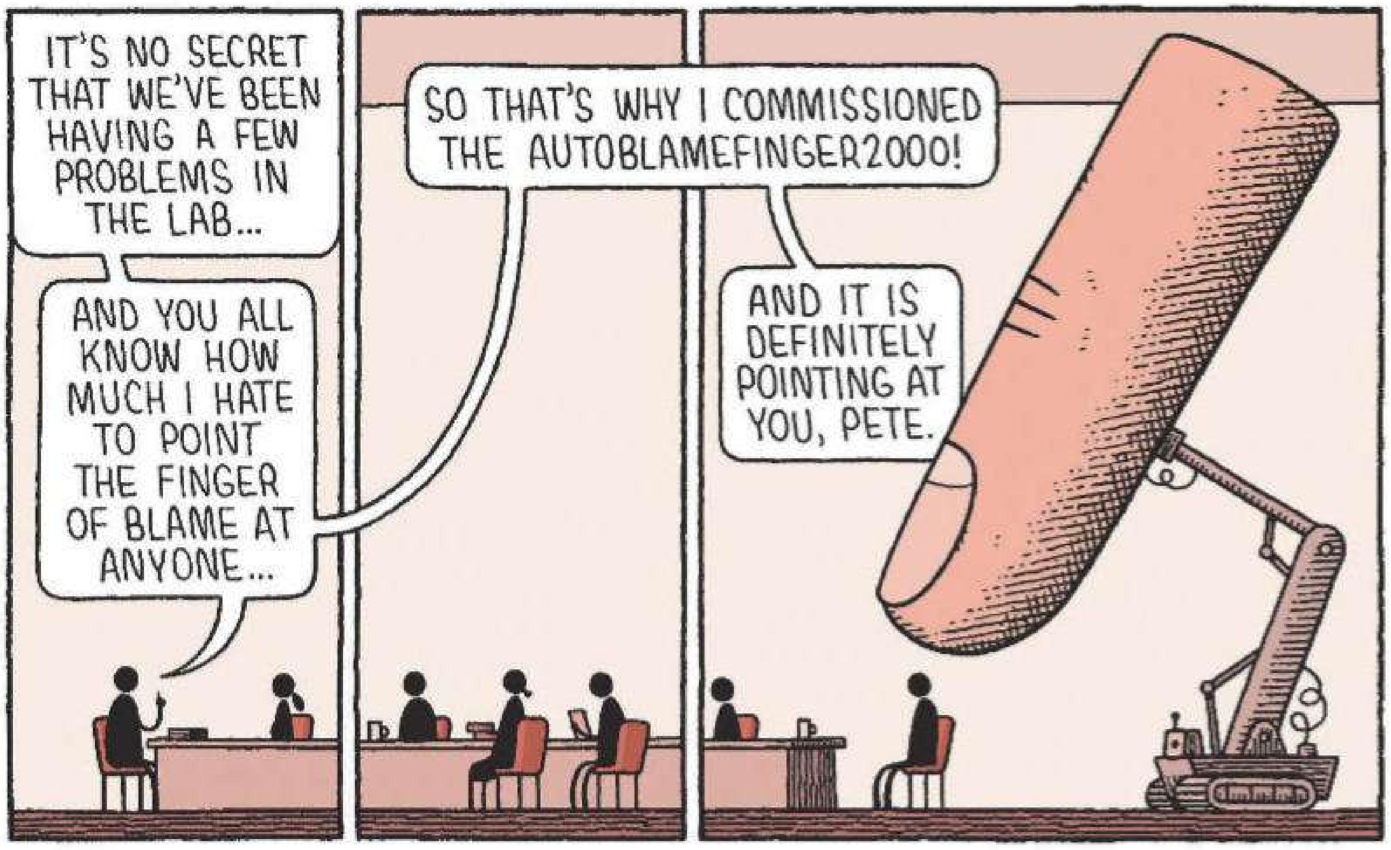

IT'S NO SECRET THAT WE'VE BEEN HAVING A FEW PROBLEMS IN THE LAB...
AND YOU ALL KNOW HOW MUCH I HATE TO POINT THE FINGER OF BLAME AT ANYONE...
SO THAT'S WHY I COMMISSIONED THE AUTOBLAMEFINGER2000!
AND IT IS DEFINITELY POINTING AT YOU, PETE.

question is their edible parts – the swelled root or, in the case of the onion, the bulb, which is actually a modified underground stem.

Known as "organs of perennation", these delicious swellings are full of starchy energy that the plants store for use in harder times, like when they are trapped in the dark refrigerator of a hungry hominin.

Plants are amazingly wired to keep growing.

Miles Rzechowicz
Canberra, Australia
Onions, carrots and radishes grow underground, where it is cold and dark, especially in the winter. The refrigerator would seem a bit like home to them.

Some vegetables have evolved or been selected to tolerate harsh conditions by forming bulbs or tubers to store energy and nutrients, which can also make those parts nutritious to eat.

These vegetables use their stored energy to send out shoots. In nature, the shoots would emerge from the soil and start to photosynthesise when they reached the light at the surface.

> **"Onions, carrots and radishes grow underground in the cold and dark. A fridge would seem a bit like home to them"**

In the refrigerator, however, there is no light, so the shoots keep on growing in a futile effort to find the sun.

David Muir
Edinburgh, UK
This is a survival strategy to help plants find the light required for photosynthesis. Prolonged time in darkness leads to plant death.

If a source of light is detected, a plant hormone called auxin, which causes plant cells to elongate, builds up in the cells on the shady side of the stem. That causes the shaded cells to stretch, leading the plant to bend towards the light.

In complete darkness, a struggling plant will respond to gravity by growing upwards in a process called gravitropism. This gives it the best chance of reaching light and surviving.

Baking boundaries

Scientifically speaking, what is the difference between a cake, a biscuit and a sponge? (continued)

Michael Zehse
via email
I am surprised that none of the previous responses (16 October) mentioned a thrilling 1991 legal case in the UK where the biscuit/cake controversy was explored at length. ▮

Ed: This legal case hinged on whether Jaffa Cakes – a popular snack originating in the UK consisting of a biscuit-sized sponge topped with chocolate – were actually biscuits rather than cakes (and thus liable to an extra tax).

A pivotal argument was that cakes harden when stale, unlike biscuits. As Jaffa Cakes harden, they were deemed cakes.

Answers

Quick quiz #127
Answers

1 Voyager 1
2 Eruciform
3 The Olmecs
4 Karel Čapek, in his play *R. U. R.*
5 Lyme disease

Quick crossword #95 *Answers*

ACROSS 8 Sudoku, **9** Her, **10** Yolk, **11** Duodecimal, **12** REXX, **13** Tsetse, **16** Spyplane, **17** Blu-rays, **18** Spassky, **22** Perianth, **25** Pascal, **26** Taxa, **27** Paramecium, **30** Zero, **31** Exe, **32** Apogee

DOWN 1 Kuru, **2** Bond, **3** Quackery, **4** Chemist, **5** Orally, **6** Hydrolysis, **7** Klaxon, **14** Sol, **15** Terminator, **19** Pap smear, **20** Kea, **21** Shorter, **23** Enamel, **24** Napier, **28** Clot, **29** Uvea

#138 Ice cream coincidence
Solution

Mr Slippy is right. As far as the digital display on the drivers' thermometers is concerned, it is possible that they clicked over at exactly the same time and never showed the same temperature. However, the actual temperature must have been the same at some point as temperature changes continuously. The graph of Van A's temperature always remained in a band between -13°C and -18°C, but the graph of Van B's temperature went outside that range and thus must have crossed over Van A's line somewhere as it went from -12°C to -20°C.

Water way to go

"REVEALED: It would cost you £17k a MONTH to live under the sea!" screams a PR email forwarded to Feedback in a typeface, colour and point size that reminds us of the days of handwritten communications in green ink.

"With Earth becoming increasingly populated and climate change causing sea levels to continuously rise, it won't be long before underwater living becomes the new normal," it continues, with a curious mixture of catastrophism and misplaced confidence. It reveals itself to be from a price comparison website that has "taken into consideration the existing price of submarine villas, as well as the top dive spots around the world to conclude how much it would cost to buy a house underwater and the best locations to live".

Don't give up the day job, we think, perhaps too snarkily – we may have no alternative if forced to commute from the seabed. A brief consultation with *Hello!* magazine and other reputable sources reveals that partially submerged villas are actually a thing, but seemingly not a thing that has spread much beyond the World Islands artificial archipelago off the coast of Dubai in the United Arab Emirates.

Developments in Dubai being not generally representative of those in the world at large, we remain sceptical. Still, something stirs in our hippocampus. These are the same people who earlier this year asserted that it wouldn't be long before lunar living became the new normal (3 April). So many new normals to choose from! With the average lunar mortgage repayment coming in at £234k a MONTH, at least submarine villas are the budget option.

Twisteddoodles *for New Scientist*

THE EARTHWORM HAS FIVE HEARTS
BUT IT CAN GAIN EXTRA HEARTS BY COMPLETING SIDE QUESTS AND BOSS BATTLES
@twisteddoodles

Got a story for Feedback?

Send it to feedback@newscientist.com or New Scientist, Northcliffe House, 2 Derry Street, London W8 5TT

Consideration of items sent in the post will be delayed

Snail spam

Feedback knows of few more pleasurable surprises in this era of over-plentiful instant messaging than receiving an old-fashioned letter. One where someone has really taken the time and effort to write personally, and we have an excuse to pop the kettle on to steam open the envelope.

So, we sympathise with the disappointment of our man who walks with the dinosaurs, Jeff Hecht. On 2 November, he received a letter at his home in Boston with a South African postmark dated 9 September. Sadly, it was no missive from a long-lost friend finding themselves unexpectedly on holiday. "The spelling and grammar are considerably better than the traditional advance fund scams I remember, and the narrative is a rather traditional one but upscaled to $250.5 million," says Jeff.

Like Jeff, Feedback is puzzled. We had considered urgent requests for funds to help those in distress in far-off lands to be a product of the email age, which allowed thousands of people to be spammed at little or no cost in the hope of finding one gullible recipient. How the economics works when every letter comes with a 14 rand ($0.92) stamp, we are unsure. Perhaps that explains the inflated sum mentioned. Perish the thought, Jeff, that they just thought you would be a sure-fire win.

Weighty comparison

Feedback is pleased to see *The Wall Street Journal* cementing its status as the spiritual and temporal home of "experiential" units rooted in no one's experience.

The newspaper's previous efforts have included comparing the speed of a volleyball serve to the maximum speed of a blimp (14 August) and explaining the tensile stress in tempered glass by asking people to "imagine an adult African male elephant suspended from a rope that's the same diameter as a table tennis ball" (27 March).

Courtesy of an article sent in by Ralf Ludwig of Melbourne Beach, Florida, discussing the craze of online investors paying ridiculous prices for tiny tungsten cubes, we now read that "They are shelling out around $400 apiece for 2-inch cubes weighing around 5 pounds, or $3,000 for the 4-inch version as heavy as a low-horsepower outboard motor".

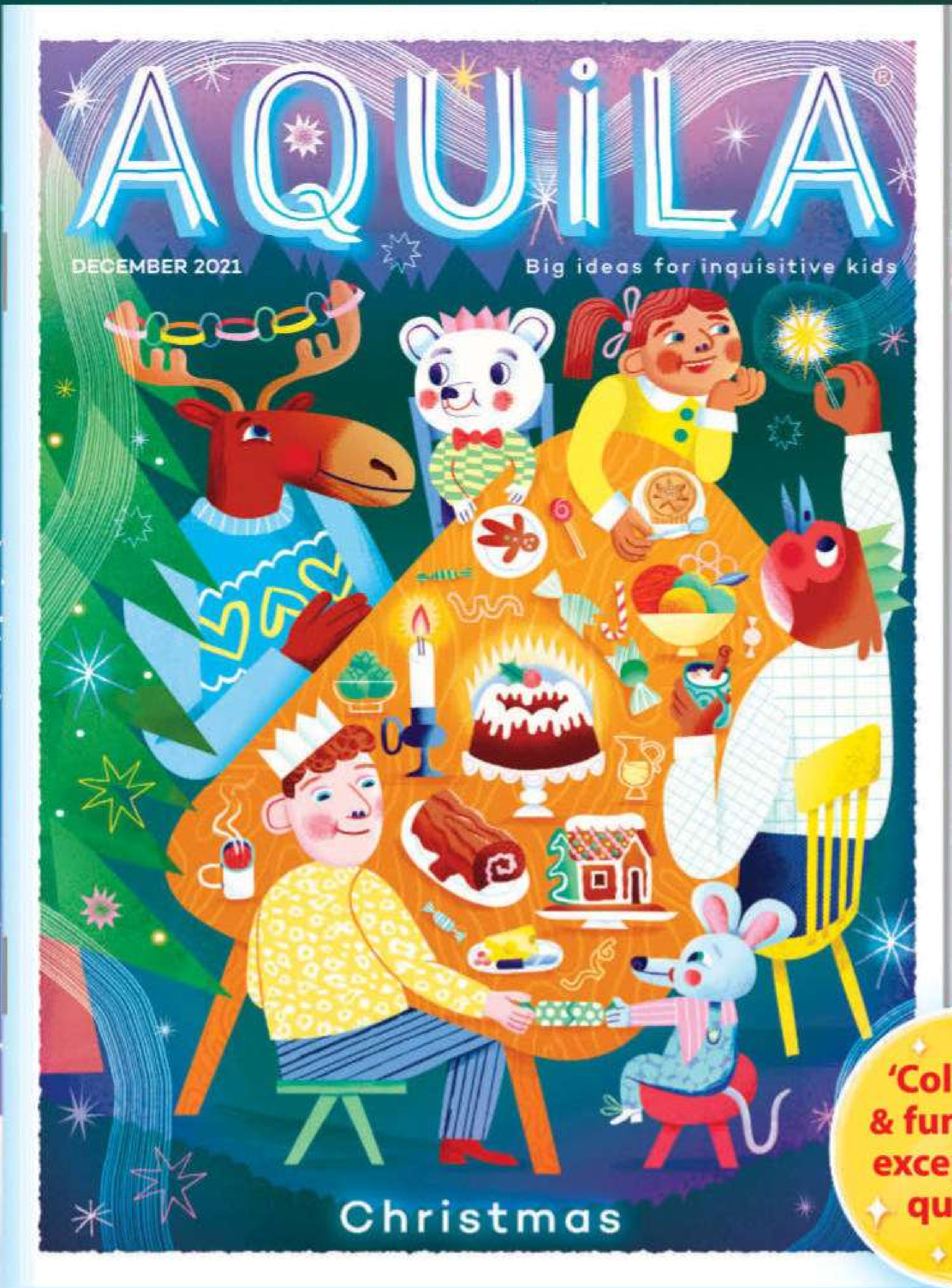
As an instantiation of value, tungsten cubes at least pass the Feedback test for "Is it art?", in that it will hurt if you drop them on your foot (1 May). As to the strangely detailed measurement comparison, we detect the culture of militant fact-checking at work here. We are a fan, even if it can lead to prose occasionally as leaden as… tungsten.

We are a convert

Ralf also wailed an enquiry about how to convert outboard motors to hippos. In answer, we might suggest Stephen Wooding's new project. He introduces himself to us by email as "a physicist and a member of the Omni Calculator Project: an international community of scientists and researchers with a goal to make science more accessible and entertaining for everyone".

He seems to be someone very much of Feedback's own heart, if the project's new Weird Units Converter is anything to go by (omnicalculator.com/conversion/weird-units). We have been whiling away many a happy minute converting distances to hair's breadths, baguettes and Great Walls of China, and powers to electric kettles and average US houses. We are pleased too to see many of our old favourites represented, such as Burj Khalifas and blue whales. But sadly no hippos, no volumes in Sydney Harbours and – shame of shames! – no areas the size of Wales. ▮

AQUILA CHILDREN'S MAGAZINE



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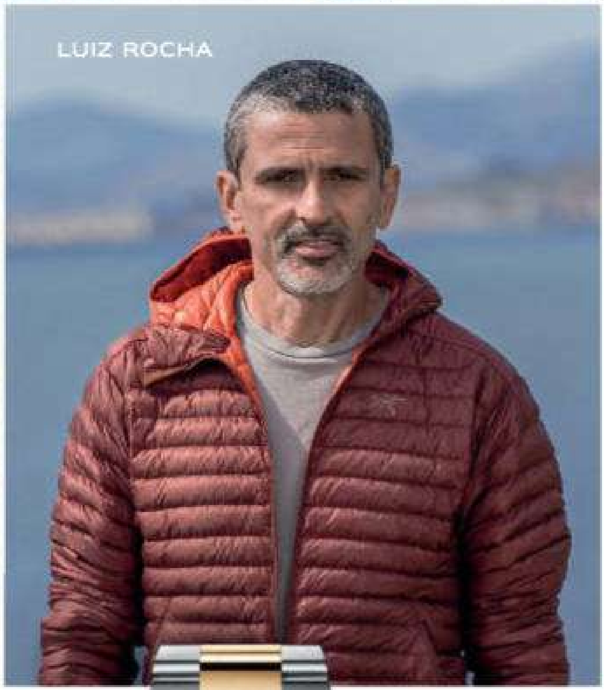

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A FUTURE WORTH PIONEERING

ROLEX AWARDS FOR ENTERPRISE. 2021 LAUREATES.

Pioneers. Guardians. These men and women spend their life's energy striving for the preservation of our planet through visionary programmes in all four corners of the Earth. Since 1976, the Rolex Awards for Enterprise have supported such pioneers and guardians of a future never certain, yet always worth reinventing. **For a perpetual planet.**

Hindou Oumarou Ibrahim, from Chad, uses indigenous peoples' traditional knowledge to map natural resources and prevent climate conflicts in the Sahel. **Luiz Rocha**, from Brazil, works to explore and protect mesophotic coral reefs and their biodiversity in the Indian Ocean, and to strengthen conservation of these largely unknown ecosystems. **Felix Brooks-church**, from the USA, tackles malnutrition in Tanzania through equipping rural flour mills with a "dosifier" machine, which adds critical micronutrients to fortify staple foods. **Rinzin Phunjok Lama**, from Nepal, works to protect the richly diverse ecosystems of the Trans-Himalayan region, home of iconic and globally threatened mammals, by involving local communities. **Gina Moseley**, from the UK, aims to lead the first expedition to explore the planet's northernmost caves to improve our knowledge into climate change in the Arctic.

#Perpetual

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